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Abstract

This paper analyzes the setting of national patent policies in the global economy. In the standard model with free trade and social-welfare-maximizing governments à la Grossman and Lai (2004), cross-border positive policy externalities induce individual countries to select patent strengths that are weaker than is optimal from a global perspective. The paper introduces three new features to the analysis: trade barriers, firm heterogeneity in terms of productivity and political economy considerations in setting patent policies. The first two features (trade barriers interacting with firm heterogeneity) tend to reduce the size of cross-border externalities in patent protection and therefore make national IPR policies closer to the global optimum. With firm lobbying creating profit-bias of the government, it is even possible that the equilibrium strength of global patent protection is greater than the globally efficient level. Thus, the question of under-protection or not is an empirical one. Based on calibration exercises, we find that there would be global under-protection of patent rights when there is no international policy coordination. Furthermore, requiring all countries to harmonize their patent standards with the equilibrium standard of the most innovative country (the US) does not lead to global over-protection of patent rights.

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1 Introduction

The global intellectual property rights (IPR) protection system was given a boost by the implementation of the TRIPS agreement (Agreement on Trade-Related Aspects of Intellectual Property Rights), which started a gradual process of IPR harmonization in 1995. This agreement effectively requires the strengthening of patent protection of many countries, and forces the world IPR protection policies towards harmonization (albeit a partial one). TRIPS is unprecedented in its ability to coordinate international IPR protection, not least because of the large number of countries involved (it is under the auspices of the WTO) and its ability to enforce rulings due to the credible threat of punishment through trade sanctions. Given the tremendous repercussions of such a coordinated increase in the strengths of IPR protection, it is fair to ask whether TRIPS is really a solution to a global coordination problem. It is clear that TRIPS creates distributive effect among countries.[1] However, the more important question is whether global IPR protection was too weak before TRIPS. If it was, then TRIPS can potentially be globally welfare-improving and therefore potentially make all countries better off. For example, if less developed countries (LDCs) lose from strengthening of their IPR and developed countries (DCs) gain from it, but the latter's gains outweigh the former's losses, then it can be mutually beneficial for the LDCs to accept (partial) harmonization of IPR standards with the DCs in exchange for the DCs' opening their markets to goods from the LDCs. However, if global patent protection was already too strong before TRIPS, then no such synergy exists between negotiations on trade-related IPR and other issues of global trade.

The objective of this paper is twofold. First, we address the question of whether global patent protection would be too weak if individual governments were left to decide their own level of protection in the absence of international coordination. Second, we seek to answer the question of whether the patent policy harmonization mandated by the TRIPS offers too much global patent protection. Both questions are important for us to evaluate the welfare consequences of TRIPS. To answer these questions, we derive conditions that entail global under-protection (or over-protection) of IPR and perform calibration exercises to check whether these conditions are satisfied.

The theoretical framework of this paper is developed by building on the work of Grossman and Lai (2004) (henceforth G-L) who develop a non-cooperative game model with free trade and

[1] McCalman (2001) has shown that the US was by far the largest beneficiary, followed by Germany and France as distant second and third beneficiaries. On the other hand, the greatest loser was Canada, followed by Brazil and UK.

social-welfare-maximizing governments.[2] It explains how a global system of patent protection affects incentives to innovate and how it creates distortions (deadweight losses). In particular, their model provides a basic theory that (a) explains how the national levels of patent protection is determined in a non-cooperative equilibrium, and (b) explains how the optimal global system of patent protection would look like.

In the basic G-L model, in the absence of international coordination, countries play a Nash game in setting the strengths of patent protection. The best response function of a country's government is obtained by setting the strength of patent protection that equates the marginal costs (deadweight loss due to longer duration of monopoly pricing) and marginal benefits (increased incentives of innovation) of extending protection, given the strengths of protection of other countries. Each country confers positive externalities on foreign countries as it extends patent protection, as it increases profits of foreign firms in the home market, and increases consumer surplus of foreign consumers due to induced innovations. As a result, there is under-protection of patent rights in Nash equilibrium relative to the global optimum. In fact, the degree of under-protection in Nash equilibrium increases with the number of independent decision-makers in the patent-setting game.

However, two factors prevents us from directly applying G-L's (2004) basic model to answer whether global patent protection would be too weak without international coordination. First, as discussed in the political economy literature, governments may put extra weight on profits as opposed to consumer surplus in their objective functions due to firm lobbying. We shall call this profit-biased preferences of governments. When governments put more weight on profits, the marginal cost of patent protection decreases since deadweight loss is smaller. Therefore, the strength of patent protection in Nash equilibrium is stronger. Second is the existence of trade barriers and firm heterogeneity. As recent empirical trade literature documents, only a small fraction of (more productive) firms sell to foreign markets. Moreover, the firms that do sell overseas have to bear trade costs, which include market entry costs, transportation costs and import tariffs. When only a fraction of domestic firms would enter a foreign market, and when there are trade costs, the positive international externalities of patent protection is diminished. Both profit-bias and trade barriers tend to diminish the degree of under-protection

[2] We start with the working assumption that the world was in a non-cooperative equilibrium before TRIPS. There is no doubt that some countries attempted to coordinate their IPR policies somewhat even before TRIPS, but empirical studies have shown that even as late as 1990, market sizes and innovative capabilities significantly affected variation in the strengths of patent protection across countries, as would be expected of a world where each country sets its own optimal IPR standard.

in Nash equilibrium relative to the global optimum. If these forces are strong enough, there may even be over-protection of patent rights in Nash equilibrium. Therefore, whether or not there is under-protection of patents in the non-cooperative equilibrium is an empirical question. To answer this question, we extend the G-L model by introducing three new elements: trade barriers, firm heterogeneity in productivity and political economy considerations. We also allow for FDI/licensing to be alternative means of serving a foreign market besides exporting.

The contributions of this paper are twofold, one theoretical and one empirical. First, we develop a model to analyze the interaction among innovation, productivity, exporting and patenting in a unified framework. By paying a fixed cost of innovation, an innovator not only develops a new product, but also earns the right to draw the cost of production from a pre-determined distribution. As there are fixed costs in exporting to or carrying out FDI in a foreign country, the more productive is a firm, the larger is the foreign market, or the stronger is IPR protection there, the more likely is the invention being exploited in the foreign market through exporting, FDI or licensing. For any given foreign market, the least productive domestic firms do not sell there, the more productive firms ship their products there, and the most productive firms set up production facilities there or license their technology to firms there. For any given firm, a foreign market would not be served by the firm if it is too small or IPR is too weak there; it will begin shipping the product there if the market is sufficiently large or IPR is sufficiently strong there; and it will begin carrying out FDI or licensing its technology there if the market is even larger or IPR is even stronger. International successes increase the profits of firms and induce more innovation. Thus, there is a positive connection between innovation in one country and patent protection in another, tempered by exporting or FDI barriers. A government is compelled to set the national strength of patent protection to maximize an objective function which is biased toward firm profits because of firm lobbying. The question is, would global patent protection still be too weak in equilibrium, given the existence of the frictions in the international exploitation of technology and profit-bias of governments? We derive a tractable framework to analyze this question.

The second contribution of the paper is that it uses data and parametric values estimated elsewhere to calibrate the theoretical model so as answer two practical questions. First, we find that global patent protection is too weak without international coordination. This is because, despite the existence of trade barriers, the free-rider problem becomes very serious when there is a large number of country-players in the patent-setting game. Second, we find that requiring all countries to harmonize their patent strengths with the equilibrium strength of the most protective country does not lead to global over-protection of IPR. This is because the distribution of innovative capability among countries is not too skewed as to overcome the free-rider effect. We therefore conclude that there is no evidence that TRIPS leads to global over-protection of patent rights.

The structure of the rest of the paper is as follows. Section 2 augments the G-L model by introducing trade barriers, firm heterogeneity and political consideration. Section 3 derive equations of the non-cooperative equilibrium and those for globally efficient patent regimes. In this section we discuss the two-country case, while in Section 4 we analyze the multi-country one. In Section 5, we calibrate the multi-country version of the model and explore empirically the questions of (i) whether there is global under-protection of IPR in the absence of international coordination and (ii) whether the harmonization mandated by TRIPS over-protects IPR globally. Section 6 concludes.

2 A theory of innovation and international patenting

The theory described in this section is basically modified from Grossman and Lai (2004) by introducing trade barriers, firm heterogeneity and profit-bias of governments.

Noncooperative Patent Protection

In this section, we study the national incentives for protection of intellectual property in a world economy with imitation and trade. For ease of exposition, we shall start with a two-country case, though we can easily generalize it to the multi-country one. We derive the Nash equilibria of a game in which two countries set their patent policies simultaneously and noncooperatively. The countries are distinguished by their wage rates, their market sizes, and their stocks of human capital, which proxies for their different capacities for R&D. For the sake of convenience, we shall term the countries "North" and "South".

Consumers in the two countries share identical preferences. In each country, the representative consumer maximizes the intertemporal utility function. The instantaneous utility of a consumer in country j is given by

$$u_j(z) = y_j(z) + \int_0^{n_S(z)+n_N(z)} h[x_j(i,z)]di, \tag{1}$$

where $y_j(z)$ is consumption of the homogeneous good by a typical resident of country j at time z, $x_j(i,z)$ is consumption of the i^{th} differentiated product by a resident of country j at time z, and $n_j(z)$ is the number of differentiated varieties previously invented in country j that remain economically viable at time z. There are M_j consumers in country j.[3] It does not matter for our analysis whether consumers can borrow and lend internationally.

In country j, it takes a_j units of labor to produce one unit of the homogeneous good or to produce one unit of any variety of the differentiated product. New goods are invented in each region according to $\phi_j = F(H_j, L_{Rj}/a_j) = A(L_{Rj}/a_j)^b H_j^{1-b}$, where H_j is an input whose quantity determines the innovative capability of country j, L_{Rj} is the labor devoted to R&D there. We assume that the numeraire good is tradeable with negligible trade costs, and that it is produced in positive quantities in both countries, so that $w_j = 1/a_j$, and hence $w_N/w_S = a_S/a_N$. Define $\overline{T} = (1 - e^{-\rho\overline{\tau}})/\rho$, where $\overline{\tau}$ is the product life of a differentiated good.

We now describe the IPR regime. Let us generalize the above description to a multi-country setting, and let there be J countries in the set $\mathcal{N}$ of country-players. In each country, there is *national treatment* in the granting of patent rights. Assume for simplicity that all unexpired patents are fully enforced. Under national treatment, the government of country j affords the same protection Ω_j to all inventors of differentiated products regardless of their national origins, where $\Omega_j = (1 - e^{-\rho\tau_j})/\rho$, and τ_j is the length of the patents granted by country j. In our model, a patent is an exclusive right to make, sell, use, or import a product for a fixed period of time (see Maskus, 2000a, p.36). This means that, when good i is under patent protection in country j, no firm other than the patent holder or one designated by it may legally produce the good in country j for domestic sale or for export, nor may the good be legally imported into country j from an unauthorized producer outside the country. We also rule out parallel imports — unauthorized imports of good i that were produced by the patent holder or its designee, but that were sold to a third party outside country j. When parallel imports are prevented, patent holders can practice price discrimination across national markets.

Recent empirical trade literature documents that only a small fraction of firms export. To capture this phenomenon, we assume that firms are heterogeneous in labor productivities (more will be said about this later). Moreover, each producer of differentiated goods is faced with trade barriers when selling abroad. They include: a fixed cost in exporting, which is denoted by F_{EX}, a fixed cost in setting up production facilities in a foreign country (which we call "carrying out FDI"), which is denoted by F_{FDI}, and a variable trade cost of the iceberg type (which consists of transport costs and import tariffs), which equals a fraction t of the production cost if a good is exported from one country to another. As a result, only a fraction of domestic firms will export to or set up production facilities in another foreign country. In

[3] We remind the reader that market size is meant to capture not the population of a country, but rather the scale of its demand for innovative products.

this paper, we do not distinguish between FDI and licensing as they can be regarded as more or less equivalent. We assume that when an innovator licenses his technology to a foreign firm, he extracts all the rents from the latter. Assuming that the licensee has to bear the same fixed and variable costs of production, FDI and licensing are equivalent.[4] Hereinafter, therefore, "FDI" shall mean "FDI or licensing". Each consumer faces a constant-elasticity demand curve, with ϵ being the price elasticity of demand. We further assume that the demand of a typical consumer is $x = Ap^{-\epsilon}$ (where $\epsilon > 1$), and define $y = (1+t)^{-\epsilon+1}$. Therefore, y is an inverse measure of the variable trade costs. As a first cut, we assume that each of the three parameters F_{FDI}, F_{EX} and t are the same across countries. It is assumed that not only is $F_{FDI} > F_{EX}$ but also $y \cdot F_{FDI} > F_{EX}$, which guarantees that firms who choose to carry out FDI in a foreign country always have the option of exporting but choose not to do so. Thus, we have a structure as depicted in Helpman, Melitz and Yeaple (2004). For any given foreign market, a firm with high unit cost of production will not sell to that market; a firm with a sufficiently lower unit cost will export to there, and a firm with a still lower unit cost will carry out FDI there. For any given firm, a sufficiently large foreign market or sufficiently strong patent protection there will induce the firm to export to that market; further increases in the market size or strength of patent protection there will eventually induce the firm to carry out FDI in that market. See Figure 3 for a graphical analysis. Define $\widetilde{\pi}(c)$ as the monopoly profit of a firm per consumer as a function of its unit cost c. The bold curve in Figure 3 is the upper envelope of three lines: 1. a horizontal line with vertical intercept 0, which represents the net profit (normalized to zero) when a foreign firm does not sell to country k; 2. the line $y\widetilde{\pi}M_k\Omega_k - F_{EX}$, which represents the net profit when a foreign firm exports to country k in addition to selling domestically; 3. the line $\widetilde{\pi}M_k\Omega_k - F_{FDI}$, which represents the profit when a foreign firm carries out FDI in country k besides selling domestically. When the value of $\widetilde{\pi}M_k\Omega_k$ lies in the range marked "Domestic Only", the upper envelope corresponds to the profit from pure domestic sales. When $\widetilde{\pi}M_k\Omega_k$ lies in the range marked "Domestic plus Export", the upper envelope corresponds to the profit from both export and domestic sales. When $\widetilde{\pi}M_k\Omega_k$ lies in the range marked "Domestic plus FDI", the upper envelope corresponds to the profit from carrying out FDI and domestic sales.

Recent political economy models indicate that politicians' desire for campaign contribution tends to bias the objective function of a government in favor of the contributors. In our model,

[4]By and large, casual observation suggests that licensing is a relatively minor channel of exploiting an invention overseas, compared with exporting and FDI. Nonetheless, we believe that in analyzing certain markets where licensing is pervasive one should include licensing as a separate mode of entry. This will be left to future research.

owners of research capital are owners of firms, who denote campaign contributions to politicians. Following the literature, we let $1+a$ be the weight a government puts on domestic profits when a weight of one is put on domestic consumer surplus in its objective function. The parameter a measures the profit-bias of governments. Note that this approach of assigning additional exogenous weight to firm profits as opposed to consumer welfare is similar to what is done in Bagwell and Staiger (2002). They essentially put a weight of $1+a$ on firms in the government's objective function, which they treat as a reduced form derived from the analysis of a political-economy equilibrium à la Grossman and Helpman (1994). Accordingly, a is also the weight a politician puts on campaign contribution when a weight of one is put on social welfare, given that his objective function is the weighted sum of the two terms.

Assume that firm productivity in each country follows a Pareto distribution: $\Pr(\frac{1}{c} < x) = 1 - \left(\frac{b}{x}\right)^{\lambda}$ where $x \in [b, \infty]$. This implies that $\Pr(c < z) = (bz)^{\lambda}$. Define π as the (unconditional) mean earnings per consumer for a monopoly selling a typical brand; define C_m as the (unconditional) mean surplus that a consumer derives from purchases of a good produced at a cost of $w_j a_j = 1$ and sold at the monopoly price p_m; and define C_c as the (unconditional) mean surplus he derives from a product sold for the competitive price of $p_c = 1$. It can be shown (in Appendix A) that

$$C_c = \frac{1}{\epsilon - 1} \cdot \frac{\lambda}{1 - \epsilon + \lambda} A b^{\epsilon - 1}$$

and

$$\pi = C_m = \Lambda C_c \qquad \text{where } \Lambda = \left(\frac{\epsilon - 1}{\epsilon}\right)^{\epsilon}.$$

It can be easily shown that the distribution of profit per consumer $\widetilde{\pi}$ is also Pareto:

$$\Pr(\widetilde{\pi} < s) = 1 - \left(\frac{A\Lambda b^{\epsilon-1}}{\epsilon - 1}\right)^{\frac{\lambda}{\epsilon-1}} \cdot s^{-\frac{\lambda}{\epsilon-1}} \quad \text{where } \widetilde{\pi} \in \left(\frac{A\Lambda b^{\epsilon-1}}{\epsilon-1}, \infty\right).$$

It can also be shown that the distribution of revenue per consumer is also Pareto, with the same shape parameter $\frac{\lambda}{\epsilon-1}$.

Axtell (2001) found that the size (number of employees) as well as revenue distribution of American firms followed a Pareto distribution $P(s, \alpha)$: $\Pr(x < s) = 1 - (s_0/s)^{\alpha}$ where $x \in (s_0, \infty)$. For the size distribution, $\alpha = 1.059$, while for revenue distribution, $\alpha = 0.994$. In other words, the estimated α for both distributions are very close to one. Luttmer (2007) finds that all possible size distributions of firms have a tail similar to Pareto distribution, with analogous tail index (equivalent to Axtell's α and our $\frac{\lambda}{\epsilon-1}$) that must be slightly above one in order to fit the data. Therefore, we shall assume $\frac{\lambda}{\epsilon-1}$ to be larger than but close to one in our calibration below.[5]

Now, define θ^k_{EX} as the probability that a foreign firm can profitably export to or carry out FDI in country k; and define θ^k_{FDI} as the probability that a foreign firm can profitably carry out FDI in country k. According to our assumptions above, if a firm can profitably export to (carry out FDI in) a larger foreign market it can also profitably export to (carry out FDI in) a smaller foreign market. Therefore, the probability that a firm in a country can profitably export to (carry out FDI in) some foreign market(s) is equal to the probability that it can profitably export to (carry out FDI in) the largest foreign market. We further define the **(inverse) international barrier to exploiting an invention in country k** as

$$\theta^k = y\left(\theta^k_{EX}\right)^{\frac{1-\epsilon+\lambda}{\lambda}} + (1-y)\left(\theta^k_{FDI}\right)^{\frac{1-\epsilon+\lambda}{\lambda}} \quad \text{for } i = 1, 2..., J. \tag{2}$$

It can be shown (in Appendix D) that in country k each consumer can only enjoy a consumer surplus equal to $\theta^k C_m$ from consuming a foreign-developed product, due to the existence of trade barriers in k. Note that $\theta^k C_m < C_m$, as trade barriers in k not only increase the cost of serving the country k market by foreign firms but also prevents some foreign firms from serving the market. Likewise, a foreign firm can only earn a profit per consumer (or user) equal to $\theta^k \pi$ from country k market due to the existence of trade barriers.[6]

It follows that the expected value of a patent of an invention by a firm in country i is given by

$$v_i = \pi\left[\sum_{k\neq i}\left(\theta^k M_k \Omega_k\right) + M_i\Omega_i\right] - \sum_{k\neq i}\left[\left(\theta^k_{EX} - \theta^k_{FDI}\right)F_{EX} + \theta^k_{FDI}F_{FDI}\right] \quad \text{for } i = 1, 2, ..., J \tag{3}$$

In general $v_i \neq v_j$ for $i \neq j$.

It can also be shown (see Appendix C) that in equilibrium

$$F_{EX} = \frac{A\Lambda b^{\epsilon-1}}{\epsilon-1} M_k \Omega_k y \left(\theta^k_{EX}\right)^{\frac{1-\epsilon}{\lambda}} \quad \text{for all } k \tag{4}$$

and therefore

$$M_{US}\Omega_{US}\left(\theta^{US}_{EX}\right)^{\frac{1-\epsilon}{\lambda}} = M_k\Omega_k\left(\theta^k_{EX}\right)^{\frac{1-\epsilon}{\lambda}} \quad \text{for all } k \neq US. \tag{5}$$

Moreover, it is shown in Appendix C that

[5] Note that we preclude the cases with $\alpha < 1$, as this would correspond to infinite mean. We are most interested in the cases when the value of α is greater than one but very close to one.

[6] A higher variable trade cost (lower y) leads to higher barrier, everything else being equal. Even if the fractions of firms that can sell overseas (θ^k_{EX}) and carry out FDI (θ^k_{FDI}) are the same, a fatter tail in the distribution of firm productivity ($\frac{\lambda}{\epsilon-1}$ closer to one) leads to lower barrier, as the firms that do export have a higher average productivity.

$$F_{FDI} - F_{EX} = (1-y)\, M_k \Omega_k \frac{A\Lambda b^{\epsilon-1}}{\epsilon-1} \left(\theta^k_{FDI}\right)^{\frac{1-\epsilon}{\lambda}} \quad \text{for all } k. \tag{6}$$

and therefore

$$M_{US}\Omega_{US} \left(\theta^{US}_{FDI}\right)^{\frac{1-\epsilon}{\lambda}} = M_k \Omega_k \left(\theta^k_{FDI}\right)^{\frac{1-\epsilon}{\lambda}} \quad \text{for all } k \neq US. \tag{7}$$

Note that $1-\epsilon < 0$. (5) and (7) therefore say that a country with stronger patent protection or a larger market tends to allow a higher fraction of foreign firms to sell to the country as well as a higher fraction of foreign firms to set up production facilities there. (4) and (6) say that given the strengths of patent protection of a country, a larger fixed cost of exporting to (carrying out FDI in) that country lowers the fraction of foreign firms that can sell to (carrying out FDI in) that country. Interestingly, (6) indicates that given the strength of patent protection of a country (call it country i), a larger variable trade cost (smaller y) or larger fixed exporting cost (larger F_{EX}) induces a higher θ^i_{FDI} and therefore a higher fraction of foreign firms doing FDI in that country. In other words, FDI serves as a substitute for exporting as trade barriers increase.

Substituting the above expressions for F_{FDI} and F_{EX}, (4) and (6), into the expression for v_i, (3), and recall that equation (2), we can re-write (see Appendix D) the expression for the value of a patent as

$$v_i = \pi \left[\sum_{k \neq i} \left(\frac{\epsilon - 1}{\lambda} \right) \theta^k M_k \Omega_k + M_i \Omega_i \right]$$

This is an interesting equation as v_i can be expressed in a very simple form though it has taken into account a myriad of factors including fixed costs of exporting and FDI, variable cost of exporting, heterogeneous firms and screening of firms by the market.

We solve the Nash game in which the governments set their patent policies once-and-for-all at time 0. These patents apply only to goods invented after time 0; goods invented beforehand continue to receive the protections afforded at their times of invention.

3 Two-country Case

Let us describe, for given patent strengths Ω_N and Ω_S, the life cycle of a typical differentiated product developed in South. In order to prevent imitation, an innovator will apply for and obtain a patent in each country immediately after the invention of the product. Then, she makes a productivity draw to find out her variable cost of production. After that, she decides whether or not to sell overseas. During an initial phase after the product is invented, the inventor holds an active patent in both countries. The patent holder earns an expected flow of profits of $\theta^N M_N \pi$ from sales in the Northern market and an expected flow of profits of $M_S \pi$ from sales in the Southern market. Each Northern consumer realizes a flow of expected surplus of $\theta^N C_m$ from his purchases of the good. A Southern consumer realizes an expected flow of consumer surplus of C_m from his purchases of the good.[7]

After a while, the patent will expire in one country. For concreteness, let's say that this happens first in the South. We assume that local firms do not have to incur the fixed cost of market entry. (Melitz 2003, for example, makes a similar assumption.) Therefore, the good will be legally imitated by competitive firms producing there for sales in the local (Southern) market. The imitators will not, however, be able to sell the good legally in the North, because the live patent there affords protection from such infringing imports. When the patent expires in the South, the price of the good falls permanently to $w_S a_S = 1$, and the original inventor ceases to realize profits in that market. The flow of consumer surplus in the South rises to $M_S C_c$.[8]

Eventually, the inventor's patent expires in the North. Then the Northern market can be served completely by competitive firms producing in the North. At this time, the price of the good in the North falls to $p_c = 1$ and households there begin to enjoy the higher flow of consumer surplus $M_N C_c$. The original inventor loses his remaining source of monopoly income. Finally, after a period of length $\bar{\tau}$ has elapsed from the moment of invention, the good becomes obsolete and all flows of consumer surplus cease.

3.1 The Best Response Functions

Consider the choice of patent policies Ω_N and Ω_S that will take effect at time 0 and apply to goods invented thereafter. The expressions for government objective function in country i,

[7] We do not address compulsory licensing and working requirement here as they do not seem to be of first order importance in the context of our analysis. Important as these issues are, we believe they should be addressed in future research.

[8] Since there is no cost of patenting, a firm always patent its good in all countries once it is developed. Once patented, the technology is disclosed. But the good cannot be legally imitated in that market until the patent expires. So, when a patent has expired consumer surplus is C_c whether a good was developed overseas or locally, as countries can always imitate foreign-developed goods when the patent has expired, and these imitated goods are produced locally, and so there is no trade barrier when imitated goods are sold.

discounted to time 0, is given by

$$
\begin{aligned}
W_i(0) &= \Lambda_{i0} + \frac{w_i L_i}{\rho} + (1+a)\frac{r_i H_i}{\rho} + \frac{M_i \phi_i}{\rho}\left[\Omega_i C_m + (\bar{T} - \Omega_i) C_c\right] + \frac{M_i \phi_{-i}}{\rho}\left[\theta^i \Omega_i C_m + (\bar{T} - \Omega_i) C_c\right] \\
&= \Lambda_{i0} + \frac{w_i (L_i - (1+a) L_{Ri})}{\rho} + \frac{M_i \phi_i}{\rho}\left[\Omega_i C_m + (\bar{T} - \Omega_i) C_c\right] \\
&+ \frac{M_i \phi_{-i}}{\rho}\left[\theta^i \Omega_i C_m + (\bar{T} - \Omega_i) C_c\right] + \frac{\phi_i}{\rho}\pi (1+a)\left[M_i \Omega_i + \theta^{-i} M_{-i} \Omega_{-i}\left(\frac{\epsilon - 1}{\lambda}\right)\right], \quad \text{for } i = S, N,
\end{aligned} \tag{8}
$$

where Λ_{i0} is the fixed amount of discounted surplus that consumers in country i derive from goods that were invented before time 0; X_{-i} or X^{-i} refers to the value of variable X pertaining to country j where $j \neq i$. The second equality arises from the fact that there is zero present-discounted profit for each firm, so that
$r_i H_i + w_i L_{Ri} = \phi_i v_i = \phi_i \pi \left[M_i \Omega_i + \theta^{-i} M_{-i} \Omega_{-i}\left(\frac{\epsilon - 1}{\lambda}\right)\right]$, where $v_i = \pi \left[M_i \Omega_i + \theta^{-i} M_{-i} \Omega_{-i}\left(\frac{\epsilon - 1}{\lambda}\right)\right]$ is the value of a new patent developed in country i.

We are now ready to derive the best response functions for the two governments. The best response expresses the strength of patent protection that maximizes a national government's objective as a function of the given patent policy of its trading partner. We assume that country i's government treats θ^i_{EX}, θ^i_{FDI} and therefore θ^i as parametric as it chooses Ω_i. Consider the choice of Ω_S by the government of the South. This country bears two costs from strengthening its patent protection slightly. First, it expands the fraction of goods previously invented in the South on which the country suffers a static deadweight loss of $M_S\left[C_c - C_m - (1+a)\pi\right]$. Second, it augments the fraction of goods previously invented in the North on which its consumers realize surplus of $\theta^S M_S C_m$ instead of $M_S C_c$. Notice that the profits earned by Northern producers in the South are not an offset to this latter marginal cost, because they accrue to patent holders in the North. The marginal benefit accrued to the South from strengthening its patent protection reflects the increased incentive that Northern and Southern firms have to engage in R&D. If the objective-maximizing Ω_S is positive and less than $\bar{T}$, then the marginal benefit *per consumer* of increasing Ω_S must match the marginal cost, which implies

$$
\begin{aligned}
& \phi_S\left[C_c - C_m - (1+a)\pi\right] + \phi_N (C_c - \theta^S C_m) \\
= \; & \frac{\gamma \phi_S}{v_S} M_S \pi \left[C_m \Omega_S + C_c (\bar{T} - \Omega_S)\right] + \frac{\gamma \phi_N}{v_N} \theta^S M_S \pi \left[\theta^S C_m \Omega_S + C_c (\bar{T} - \Omega_S)\right],
\end{aligned} \tag{9}
$$

where γ is the responsiveness of innovation in each region to changes in the value of a patent (in elasticity form), i.e. $\frac{\partial \phi_j}{\partial v_j} = \gamma \frac{\phi_j}{v_j}$.[9]

[9] It can be easily shown that $\gamma_i = \frac{b}{(1-b)}$ for all i.

It is straightforward to write down the condition for the best response of the North, analogous to (9) above, so we do not put it here in the interest of space.

The two best response functions can be written similarly as

$$\begin{aligned} & \mu_{-i}\left(1-\theta^i\Lambda\right)+\mu_i\left[1-\Lambda-(1+a)\Lambda'\right] \\ = \; & \frac{\gamma M_i\left\{\mu_i\left[1-(1-\Lambda)\omega_i\right]+\theta^i\mu_{-i}\left[1-\left(1-\theta^i\Lambda\right)\omega_i\right]\right\}}{M_i\omega_i+\theta^i M_{-i}\omega_{-i}\left(\frac{\epsilon-1}{\lambda}\right)} \quad \text{for } i=S,N, \end{aligned} \tag{10}$$

where $\Lambda = C_m/C_c$, $\Lambda' = \pi/C_c$, $\omega_i = \Omega_i/\overline{T}$ and $\mu_i = \phi_i/(\phi_S+\phi_N)$ is the share of world innovation that takes place in country i. Moreover, $\mu_i = H_i/(H_S+H_N)$ when $\frac{\lambda}{\epsilon-1}=1$.[10] Thus, μ_i is unaffected by patent policies when $\frac{\lambda}{\epsilon-1}=1$. Given that $\frac{\lambda}{\epsilon-1}$ is sufficiently close to one, which has been justified by empirical research findings, we can show from (10) that the best response functions are downward sloping, and that the best response function for the South is everywhere steeper than that for the North, when the two are drawn in (Ω_S, Ω_N) space. It follows that the curve for the South must be steeper than that for the North at any point of intersection. This guarantees uniqueness of the Nash equilibrium and ensures stability of the policy setting game.

3.2 International Patent Policy Coordination

In this section, we study the welfare impacts of international patent policy coordination. We begin by characterizing the combination of patent policies that are jointly efficient for the two countries. We then compare the Nash equilibrium outcome with the efficient policies, to identify changes in the patent regime that ought to be effected by an international agreement.

Efficient Patent Regime

Let $Q_S = M_S\Omega_S + \theta^N M_N\Omega_N$. A Southern firm that earns a flow of expected profits of $M_S\pi$ for a period of length τ_S in the South and a flow of expected profits of $\theta^N M_N\pi$ for a period of τ_N in the North earns a total discounted sum of expected profits equal to $Q_S\pi$. On the other hand, a Northern innovator earns a total discounted sum of expected profit equal to $Q_N\pi$ where $Q_N = \theta^S M_S\Omega_S + M_N\Omega_N$.

Consider the choice of patent policies Ω_N and Ω_S that will take effect at time 0 and apply to goods invented thereafter. Equation (8) becomes an expression for welfare when $a = 0$.

[10] When $\frac{\lambda}{\epsilon-1}=1$, $\theta^i=1$ for all i, and so $v_i = v$ for all i. Consequently, $\mu_i = H_i/(H_S+H_N)$.

Summing the expressions in (8) for $i = S$ and $i = N$ with a set to zero, we find that

$$\rho\left[W_S(0) + W_N(0)\right] = \rho\left(\Lambda_{S0} + \Lambda_{N0}\right) + w_S(L_S - L_{RS}) + w_N(L_N - L_{RN}) + \left[M_S \bar{T} C_c - M_S \Omega_S \left(C_c - C_m - \pi\right)\right]\left(\phi_S + \theta^S \phi_N\right) + \left[M_N \bar{T} C_c - M_N \Omega_N \left(C_c - C_m - \pi\right)\right]\left(\phi_N + \theta^N \phi_S\right) \quad (11)$$

There is clearly a tradeoff as patent strength is increased in either country. For example, as Ω_S increases there is a direct effect of an increase in the deadweight loss $M_S \Omega_S \left(C_c - C_m - \pi\right)$, which lowers global welfare. But there are indirect effects that tend to increase global welfare: an increase in Ω_S leads to an increase in Q_N (Q_S), which induces faster innovation in the North (South), thus increasing ϕ_N (ϕ_S) and L_{RN} (L_{RS}). These effects are globally welfare-improving. In fact, it can be shown that when $\frac{\lambda}{\epsilon - 1}$ is sufficiently small, there exists a unique globally optimum combination of Ω_N and Ω_S.

How do the efficient combination of patent policies compare to the policies that emerge in a noncooperative equilibrium? The answer to this question — which informs us about the likely features of a negotiated patent agreement — is illustrated in Figure 1. The figure depicts the best response functions and the efficient policy combination on the same diagram.

<Figure 1 about here>

In this figure, the globally optimal policy combination is depicted by point G. The iso-global-welfare lines around G are also shown. The diagram shows that simultaneous increases of Ω_N and Ω_S from point E leads to an increase in global welfare. This is true when a is small, i.e. when government's profit-bias is weak. The reasons are clear. Starting from a point on the South's best response function, a marginal strengthening of IPR protection in the South increases the world's welfare when profit-bias is weak. Such a change in Southern policies has only a second-order effect on the welfare of the South, but it conveys two positive externalities to the North. First, it provides extra monopoly profits to Northern innovators, which contributes to the aggregate income there. Second, it enhances the incentives for R&D, inducing an increase in both ϕ_S and ϕ_N. The extra product diversity that results from this additional R&D creates additional surplus for Northern consumers.

By the same token, a marginal increase in the strength of Northern patent protection from a point along NN increases world welfare. Such a change in policy enhances the profit income of the Southern firms and encourages additional innovation in both countries. It follows that when a is small, world welfare rises as Ω_N and Ω_S simultaneously increase from point E. However, if

a is not "small", then it is possible that an efficient patent treaty may require all countries to reduce their strengths of patent protection. Whether or not a is small in practice is an empirical question, which we seek to answer in the Section 5.

We define global under-protection of patent rights to be a situation when global welfare rises as Ω_N and Ω_S are both raised from their Nash equilibrium levels. If there is under-protection of patent rights, then starting from any interior Nash equilibrium, an efficient patent treaty must strengthen patent protection in both countries. It also implies that the treaty will strengthen global incentives for R&D and induce faster innovation in both countries.

4 Multi-country Case

Before bringing the model to the data, it is useful to extend the model to a multi-country setting, as the number of independent decision-making governments plays a crucial role in whether there is under-protection of IPR in Nash equilibrium. Recall that there are J countries in the set N of country-players. Define $f_i \equiv C_c\overline{T} - (C_c - C_m)\,\Omega_i$ as the present discounted value of consumer surplus for a consumer in country i derived from the consumption of a home-developed differentiated good over its product life; and $f_i' \equiv C_c\overline{T} - \left(C_c - \theta^i C_m\right)\Omega_i$ as the corresponding consumer surplus derived from the consumption of a product developed by a foreign country.

Nash Equilibrium

In a multi-country setting, the best-response function of country i is

$$\begin{aligned}
&\underbrace{\left(\sum_{j\neq i}\phi_j\right)\left(C_c - \theta^i C_m\right) + \phi_i\left(C_c - C_m\right) - \phi_i\left(1+a\right)\pi}_{\text{marginal cost}} \\
= &\left(\sum_{j\neq i}\frac{\partial\phi_j}{\partial v_j}\frac{\partial v_j}{\partial\Omega_i}f_i'\right) + \frac{\partial\phi_i}{\partial v_i}\frac{\partial v_i}{\partial\Omega_i}f_i \\
= &\underbrace{\left(\sum_{j\neq i}\gamma\frac{\phi_j}{v_j}\right)\theta^i\pi M_i f_i' + \gamma\frac{\phi_i}{v_i}\pi M_i f_i}_{\text{marginal benefit}} \quad \text{for } i = 1,2,...,J
\end{aligned} \tag{12}$$

The *left-hand side (LHS)* of equation (12) is, in fact, the marginal cost per consumer in country i of strengthening IPR there. The first term is the loss in consumer surplus attributed to protection of inventions from firms outside country i (note that while patent protection is in force in country i, each consumer only enjoys consumer surplus of $\theta^i C_m$ from each foreign-developed product, but when the patent protection ceases, domestic firms can imitate the good at no cost, and so each consumer obtains consumer surplus of C_c from the good); the second term is the loss of consumer surplus attributed to protection of inventions from country i; and the third term is the gains in profits of firms in country i, which offsets the losses of consumer surplus. The *right-hand side (RHS)* or the third line of (12) is the marginal benefit per consumer in country i. The first term is the increase in consumer welfare in country i due to increases in flows of innovations from firms outside country i; the second term is the increase in consumer welfare in country i due to the increase in the flow of innovation from country i. If we define the left-hand side of (12) as $MC_i(a)$ and the right-hand side of (12) as MB_i, then $\frac{1}{M_i}\frac{\partial W_i(a)}{\partial \Omega_i} = MB_i - MC_i(a)$, where $W_i(a)$ is Government i's objective function. (Hereinafter, we put an argument 'a' after the name of a function if profit-bias affects the value of the function.)

Equation (12) can be re-written as

$$\begin{aligned}
&\left(\sum_{j\neq i}\phi_j\right)\left(1-\Lambda\theta^i\right)+\left[1-(2+a)\Lambda\right]\phi_i \\
=\;& \gamma\left\langle \sum_{j\neq i}\left\{\frac{\phi_j\theta^i M_i\left[1-\left(1-\Lambda\theta^i\right)\omega_i\right]}{\sum_{k\neq j}\left(\frac{\epsilon-1}{\lambda}\right)\left(\theta^k M_k\omega_k\right)+M_j\omega_j}\right\}+\frac{\phi_i M_i\left[1-(1-\Lambda)\omega_i\right]}{\sum_{k\neq i}\left(\frac{\epsilon-1}{\lambda}\right)\left(\theta^k M_k\omega_k\right)+M_i\omega_i}\right\rangle \\
&\text{for } i=1,2,...,J, \qquad (13)
\end{aligned}$$

where $\omega_k \equiv \Omega_k/\overline{T}$ and $\Lambda \equiv C_m/C_c$. In order to solve for the values of ω_i, for $i = 1, 2, ..., J$, we also need equations (2), (5), and (7), as well as the calibrated value of θ^R_{EX} and θ^R_{FDI}, where the superscript R denotes the country with the largest market outside of the US. It turns out that R is Japan. We shall adopt $\theta^R_{EX} = 0.15$ and $\theta^R_{FDI} = 0.03$ based on the estimates of the fractions of American firms that export and of those that carry out FDI in foreign countries, as provided in Eaton, Kortum and Kramarz (2004) and Bernard, Eaton, Jensen and Kortum (2003). More discussion will be provided about this in the next section.

As discussed above, $\frac{\lambda}{\epsilon-1}$ should be larger than one but very close to one according to Axtell (2001). The best response function of country i when $\frac{\lambda}{\epsilon-1} = 1$ is given by

$$\left(\sum_k \phi_k\right)(1-\Lambda)-(1+a)\Lambda\phi_i = \frac{\gamma\left(\sum_k\phi_k\right)M_i\left[1-(1-\Lambda)\omega_i\right]}{\sum_k M_k\omega_k} \quad \text{for } i=1,2,...,J \qquad (14)$$

Amazingly, this is mathematically equivalent to assuming that there is neither variable nor fixed trade costs. Therefore, the general case collapses to the free-trade case when $\frac{\lambda}{\epsilon-1} = 1$. A value closer to one entails a fatter tail of the distribution, meaning the existence of more giant firms. As $\lambda/(\epsilon-1)$ tends to 1 from above, the distribution has a mean that approaches infinity, suggesting the predomination of large firms. The intuition is that when a significant portion of the firms earn very high profits, trade costs become inappreciable and hence are no longer effective in hindering trade. As the free-trade case (with J linear equations in J unknowns ω_i for $i = 1, 2, ..., J$) is much easier to compute than the more general case (where $\frac{\lambda}{\epsilon-1} > 1$ and there are $4J-2$ equations and $4J-2$ unknowns), we start our analysis by assuming $\frac{\lambda}{\epsilon-1} = 1$ and then proceed to relax this assumption. This provides a good benchmark and a good approximation of the more general case when $\frac{\lambda}{\epsilon-1}$ is greater than but close to one.

Global Optimum

Next, we turn to the comparison between the Nash equilibrium and the global optimum. It can be shown that the first-order condition for global welfare maximization with respect to the choice of Ω_i is given by

$$\begin{aligned} & M_i\left[MC_i(a) + \pi a\phi_i - \theta^i\pi\left(\sum_{j\neq i}\phi_j\right)\right] \\ = \quad & M_i \times MB_i + \sum_{k\neq i}\left(\sum_{j\neq k}\frac{\partial\phi_j}{\partial v_j}\frac{\partial v_j}{\partial\Omega_i}M_k f_k'\right) + \sum_{k\neq i}\frac{\partial\phi_k}{\partial v_k}\frac{\partial v_k}{\partial\Omega_i}M_k f_k \\ = \quad & M_i \times MB_i + \sum_{k\neq i}\left[M_k\left(\gamma\frac{\phi_i}{v_i}M_i\pi f_k'\right) + M_k\left(\sum_{j\neq k,i}\gamma\frac{\phi_j}{v_j}\right)\theta^i M_i\pi f_k'\right] + \sum_{k\neq i}M_k\left(\gamma\frac{\phi_k}{v_k}\theta^i M_i\pi f_k\right) \end{aligned} \tag{15}$$

The *LHS* of (15) (call it LHS_{15}) is the marginal global cost of strengthening IPR protection in that country. The second term inside the squared brackets $(\pi a\phi_i)$ is the welfare that will not be taken into account when IPR protection in country i is chosen to maximize the global welfare instead of government i's profit-biased objective function (therefore it is an addition to marginal cost); the third term inside the squared brackets ($\theta^i\pi\left(\sum_{j\neq i}\phi_j\right)$) reduces the global marginal cost as it takes into account the increases in profits of firms outside of country i. The *RHS* (or the third line) of (15) (call it RHS_{15}) represents the marginal global benefit of strengthening IPR in country i. The second term and the third term are both increases in welfare of consumers outside of country i. The second term is due to faster foreign innovations, while the third term is due to faster domestic innovations ("foreign" and "domestic" here are relative to each country other than country i). The cross-border externalities of IPR protection are captured by the third term inside the squared brackets on the LHS plus the second and third terms on the RHS. It is apparent that since an increase in the variable trade cost (a decrease in y) leads to less international spillovers, the likelihood of under-protection of IPR in equilibrium is lower. Likewise, an increase in profit-bias (an increase in a) reduces the gap between marginal global benefit and marginal national benefit, making under-protection of IPR less likely.

Let us define LHS_{15}/M_i as MC_i^w and RHS_{15}/M_i as MB_i^w. It follows that $\frac{1}{M_i}\frac{\partial W^w}{\partial \Omega_i} = MB_i^w - MC_i^w$, where W^w denotes the world welfare (without any bias in favor of firm profits).

5 Empirical Analysis

5.1 Is there global under-protection of IPR?

We define under-protection as a situation when, starting from Nash equilibrium, global welfare increases when there are positive changes in some or all of $\{\Omega_i | i \in \mathcal{N}\}$ (where the magnitudes of increase need not be equal across countries). The point of the analysis is to come up with a sufficient condition under which, starting from Nash equilibrium $\left\{\Omega_i^E \middle| i \in \mathcal{N}\right\}$, some simultaneous (but not necessarily equal) increases in IPR protection of some or all countries is globally welfare-improving. Note that an increase in the strength of protection in some or all countries raises the values of all patents. This increases the global deadweight losses but encourages innovation. If there is global under-protection of patent rights, then the rate of innovation in the world is too low from a global welfare point of view. To simplify the analysis, we focus on changes in $\{\Omega_i | i \in \mathcal{N}\}$ such that $M_i d\Omega_i = \delta$ for all i, where δ is a constant. It is a case where the increase in the patent protection of each country is proportional to the inverse of its market size. Countries with smaller market size thus need to raise their patent protection by a larger extent than countries with larger market size. In this setting, we derive a sufficient condition under which such changes lead to an increase in global welfare. In other words, we seek a condition under which the marginal global benefit outweighs the marginal global cost.

We first prove the following lemma:

Lemma 1. A sufficient condition for under-protection of IPR in Nash equilibrium is

$$\sum_i \frac{1}{M_i}\frac{\partial W^w}{\partial \Omega_i} > 0 \text{ for all } \{\Omega_i | i \in \mathcal{N}\} \text{ such that } \sum_i \frac{1}{M_i}\frac{\partial W_i(a)}{\partial \Omega_i} = 0. \tag{16}$$

This lemma provides a condition under which simultaneous strengthening of patent protection in all countries from the Nash equilibrium levels is globally welfare improving. The set of Nash equilibrium strengths of patent protection $\left\{\Omega_i^E \middle| i \in \mathcal{N}\right\}$ satisfy $\sum_i \frac{1}{M_i}\frac{\partial W_i(a)}{\partial \Omega_i} = 0$ as the best response function of country j is given by $\frac{1}{M_j}\frac{\partial W_j(a)}{\partial \Omega_j} = 0$. On the other hand, $\sum_i \frac{1}{M_i}\frac{\partial W^w}{\partial \Omega_i} > 0$ means that simultaneous increases of Ω_i can raise global welfare W^w.

Proof. A sufficient condition for under-protection is

$$\sum_i \frac{1}{M_i}\frac{\partial W^w}{\partial \Omega_i} > 0 \ \text{ in Nash equilibrium } \left\{ \Omega_i^E \middle| \, i \in \mathcal{N} \right\}.$$

This is true because $\sum_i \frac{1}{M_i}\frac{\partial W^w}{\partial \Omega_i} > 0$ implies that if we increase each Ω_i in $\left\{ \Omega_i^E \middle| \, i \in \mathcal{N} \right\}$ such that $M_i d\Omega_i = \delta \ \ \forall i$, where δ is a constant, then $dW^w = \left(\sum_i \frac{\partial W^w}{\partial \Omega_i} d\Omega_i\right) = \left(\sum_i \frac{1}{M_i}\frac{\partial W^w}{\partial \Omega_i}\right)\delta > 0$. That is, global welfare increases as each Ω_i increases slightly such that $\frac{d\Omega_i}{d\Omega_j} = \frac{M_j}{M_i}$ for all $i \neq j$. This clearly indicates under-protection at Nash equilibrium. Moreover, since $\frac{\partial W_i(a)}{\partial \Omega_i} = 0$ for all i in Nash equilibrium, $\sum_i \frac{1}{M_i}\frac{\partial W_i(a)}{\partial \Omega_i} = 0$ includes the Nash equilibrium as a special case. ■

To understand Lemma 1 better, let us consider a two-country case. First refer to Figure 1 for an idea of the relationship between Nash equilibrium and global optimum. In that diagram, point E is the Nash equilibrium while point G is the global optimum. BRF-S and BRF-N are the best response functions of South and North respectively. Point G is at the intersection of the curves $\frac{\partial W^w}{\partial \Omega_S} = 0$ and $\frac{\partial W^w}{\partial \Omega_N} = 0$, which are not shown.[11] It is not hard to see that starting from any point on the iso-global-welfare line to the left of GG (defined by $\frac{1}{M_S}\frac{\partial W^w}{\partial \Omega_S} + \frac{1}{M_N}\frac{\partial W^w}{\partial \Omega_N} = 0$), any small increase in Ω_S and Ω_N such that $\frac{d\Omega_N}{d\Omega_S} = \frac{M_S}{M_N}$ would increase W^w. This implies that, in the context of Figure 1, a necessary and sufficient condition for there to be under-protection in Nash equilibrium is that point E is to the left of the curve GG.[12]

<Figure 2 about here>

Figure 2 shows the relationship between the curves GG and EE (defined by $\frac{1}{M_S}\frac{\partial W_S(a)}{\partial \Omega_S} + \frac{1}{M_N}\frac{\partial W_N(a)}{\partial \Omega_N} = 0$). The curves FOC-S (defined by $\frac{1}{M_S}\frac{\partial W_S(a)}{\partial \Omega_S} = 0$) and FOC-N (defined by $\frac{1}{M_N}\frac{\partial W_N(a)}{\partial \Omega_N} = 0$) are the first order conditions for the maximization of global welfare with respect to the choice of Ω_S and Ω_N respectively. In the context of Figure 2, a sufficient condition for point E to be on the left of GG is that EE is to the left of curve GG. And this is exactly the sufficient condition for under-protection (16) stated in Lemma 1. If this condition is satisfied, at any point that lies on EE (including the Nash equilibrium point E), any small change in Ω_S and Ω_N such that $M_S d\Omega_S = M_N d\Omega_N$ would increase global welfare, since $\frac{1}{M_S}\frac{\partial W^w}{\partial \Omega_S} + \frac{1}{M_N}\frac{\partial W^w}{\partial \Omega_N} > 0$. Proposition 1 below provides a sufficient condition for the EE to be on the left of GG. Therefore, our next step is to prove the following proposition:

[11] Note that the slopes of the iso-global-welfare lines $W^w = \overline{W}$ are always equal to $\frac{M_S}{M_N}$ at their intersection with the line $\frac{1}{M_S}\frac{\partial W^w}{\partial \Omega_S} + \frac{1}{M_N}\frac{\partial W^w}{\partial \Omega_N} = 0$. This is because, along $W^w = \overline{W}$, $\frac{d\Omega_N}{d\Omega_S} = -\left(\frac{\partial W^w}{\partial \Omega_S} / \frac{\partial W^w}{\partial \Omega_N}\right)$. But at any point on the curve $\frac{1}{M_S}\frac{\partial W^w}{\partial \Omega_S} + \frac{1}{M_N}\frac{\partial W^w}{\partial \Omega_N} = 0$, we have $-\left(\frac{\partial W^w}{\partial \Omega_S} / \frac{\partial W^w}{\partial \Omega_N}\right) = \frac{M_S}{M_N}$.

[12] Note that if point E is to the right of GG, then any simultaneous small decrease of Ω_S and Ω_N such that $\frac{d\Omega_N}{d\Omega_S} = \frac{M_S}{M_N}$ would increase W^w.

Proposition 1 *A sufficient condition for under-protection of IPR in Nash equilibrium when there are trade barriers and profit-bias is*

$$a - \sum_{i \neq \max} \theta^i < 0 \tag{17}$$

where $\theta^{\max}$ is the largest θ^i among all countries. This means that the positive force on the equilibrium strengths of patent protection that arises from profit-bias (measured by a) is weaker than the negative force that arises from positive cross-border externalities due to the existence of a large number of government-players (measured by $\sum_{i \neq \max} \theta^i$), thus making the Nash equilibrium more likely to yield under-protection.

Proof. See Appendix E. ■

To check that $a - \sum_{i \neq \max} \theta^i < 0$ is a reasonable condition, note that in the special case of the basic model where there are two countries ($J = 2$) and there is neither trade barrier nor profit-bias (i.e. with $y = 1$, $\theta^i = 1$ for $i = 1, 2$ and $a = 0$), the condition is satisfied. Moreover, it accords with the intuition that the free-rider problem gets more serious when there are more countries playing the patent-setting game, for a larger J leads to higher chance of under-protection. It also is consistent with the notions that trade barriers weaken the cross-border externality of IPR protection, because a smaller θ^i for each i leads to lower chance of under-protection, and that stronger government bias towards patent-holding firms tends to strengthen patents, for a larger a leads to lower chance of under-protection. In what follow, we shall explain a calibration exercise to find out whether the above sufficient condition is satisfied. We shall solve equations (13), (2), (5), (7) for $i = 1, 2, ..., J$ with parametric values calibrated using estimates in the extant literature.

The parameter a captures the degree of profit-bias in governments' objective functions. In the political-economy literature (Grossman and Helpman, 1994; Maggi and Goldberg, 1999; Gawande et al., 2000; Mitra et al., 2002; Eicher and Osang, 2002; McCalman, 2004 and Mitra et al., 2006), researchers have estimated the weight the U.S. government puts on campaign contributions given a weight of unity on social welfare. The values range from 0.000315 to 1.3333. For robustness check in the calibration exercises, we set a to the extremes of parameter estimates in the extant literature as well as to a benchmark value of 1. We tried the values of $a = 0.000315$ (low profit-bias), 1 (strong profit-bias) and 1.3333 (very strong profit-bias), but only report the case of $a = 1.333$ in the interest of space.[13]

[13]Since a a preference parameter, it should be the same in the context of patent protection. Suppose there is

The parameter J denotes the number of independent government decision-makers in the patent-setting game. Thus, it is the number of countries in the world that consume and trade patent-sensitive goods, and that adopt neither zero nor full patent protection. In Table 1, we list the patent counts and market sizes of the twenty largest markets for patent-sensitive goods among the forty most innovative countries.[14] As the sufficient condition for under-protection in the Nash equilibrium (inequality (17)) indicates, the more countries that are included in the game, the more likely the condition is satisfied. Therefore, it suffices to prove under-protection if we find that the inequality holds for the twenty countries with the largest markets for patent-sensitive goods. These countries are thus included in our empirical analysis, which gives $J = 20$.

<Table 1 about here>

θ^i_{EX} and θ^i_{FDI} respectively the probabilities that foreign firms can export and carry out FDI in country i. Eaton, Kortum and Kramarz (2004) report that in 1986 only 17.4% of French manufacturing firms exported, and of those who exported, only 19.7% exported to ten or more countries. Moreover, in 1987, only 14.6 % of US manufacturing firms exported. Bernard, Eaton, Jensen and Kortum (2003) report that 79% of US manufacturing plants did not export at all in 1992. A summary the existing studies in the literature indicate that 15-20% of manufacturing firms sell to foreign markets, of which about 1/5 produce in the foreign market in which they sell. (See, for example, Bernard, Jensen and Schott, 2009). Patent-sensitive goods are likely to be more tradeable than the average manufactured good. Therefore, to be conservative, we assume that 15% of American firms in the patent-sensitive industries sell to foreign markets, while 3% produce in the foreign countries in which they sell their goods. In other words, we set $\theta^{Japan}_{EX} = 0.15$ and $\theta^{Japan}_{FDI} = 0.03$ as Japan is the largest foreign market for US firms. The θ^i_{EX} and θ^i_{FDI} for other countries are determined endogenously by equations (5) and (7) respectively.

We estimate γ based on the work of Boldrin and Levine (2009), which suggests a point estimate of around 4.[15] As we find that our results are robust to alternative values of γ, we just report the case of $\gamma = 4$ in this paper.

a patent lobby, and suppose there is no consumer lobby or lobbying from other sectors of the economy, it is easy to show that the value the government puts on campaign contributions is exactly the same as a in our model. A proof is available from the author upon request.

[14] Innovative capability is measured by the number of patents granted to domestic residents of the country by the US patent office per year over the years 1996-1999. Russia is not included due to the lack of reliable data. See Appendix F.

[15] Details of the derivation can be obtained from the authors upon request.

Lai, Wong and Yan (2007) estimate the parametric values of the elasticity of demand of patent-sensitive goods (ϵ) across thirty countries. These values average to 5.63. Given this, we assume $\epsilon = 5$. This coincides with the value implied by putting together the findings of literature that the shape parameter of the Pareto distribution of firm revenues ($\frac{\lambda}{\epsilon-1}$ in our model) is close to 1 and the finding of Simonovska (2011) that λ is approximately 4. For robustness, we also try a low elasticity scenario with $\epsilon = 1.5$ and a high elasticity scenario with $\epsilon = 9.28$. The upper value of 9.28 is obtained based on $\frac{\lambda}{\epsilon-1} \approx 1$ and the finding of Eaton and Kortum (2002) that λ is approximately 8.28.

As $\lambda/(\epsilon-1)$ tends to 1 from above, the tail of the distribution gets fatter, and the distribution has a mean that approaches infinity, suggesting the predomination of large firms. It is interesting that the special case of $\lambda/(\epsilon-1) \to 1$ converges to the free trade case in our model, as explained earlier. The literature (e.g. Axtell (2001) and Luttmer (2007)) finds that the scale parameter of the Pareto distribution is very close to one but above one. In this paper, we report the cases of $\lambda/(\epsilon-1) = 1$ and $\lambda/(\epsilon-1) = 1.049$, as these two values lie roughly at the two ends of the spectrum of estimates obtained in the literature. Adopting this range also ensures that there are interior solutions to all endogenous variables of interest.

For the variable trade cost, we try a wide range of values from $t = 0$ (no iceberg trade cost) to 0.5 (very high iceberg trade cost). For the case $\lambda/(\epsilon-1) = 1$, the results are invariant to the value of t.

We proxy the market size (M_i) by the natural logarithm of the dollar value of the consumption of patent-sensitive goods in each country and proxy the innovative capability (ϕ_i) by the number of patents granted to residents of each country by the U.S. patent office divided by the population of the country (we adjust for home bias of American patentees).[16] Data on M_i for 1996-1999 are obtained from Lai, Wong and Yan (2007), and data on ϕ_i for 1996-1999 are from the website of WIPO.

Based on the above parametric values and data, we solve for the Nash equilibrium values of $\left\{\omega_i^E, \theta^i, \theta^i_{EX}, \theta^i_{FDI} \middle| \ i \in \mathcal{N}\right\}$ from equations (13), (2), (5), (7) for $i = 1, 2, ..., J$. The calibration results are presented in Table 2. A wide range of values of profit-bias have been tried ($a = 0.000315, a = 1$ and $a = 1.3333$) but it has relatively minor effects on θ^i. So we only report the results for the most conservative case of $a = 1.3333$ in the interest of space.

[16] We also tried using the patent counts without dividing by population to proxy for innovative capability, and the sufficient condition for under-protection (17) is still satisfied. But the rank order of ω_i^E matches closer the actual rank order of the Ginarte-Park indexes (which measure patent rights) when we use patent counts divided by population.

<Table 2 about here>

This calibration exercise yields two important results. First, we find that the values of θ^i are above 0.7 for all countries under all scenarios. It follows that the sufficient condition for under-protection of IPR in the Nash equilibrium specified in equation (17) is satisfied under all parameter values considered. As a result, **we conclude that there is under-protection of patent rights when there is no international coordination**. The major reason is the existence of the free-rider problem in the protection of patents, which becomes very serious when there is a large number of government-players in the patent-setting game.

Second, this sensitivity analysis allows us to assess the role played by each of the three channels separately — namely, profit-bias, firm heterogeneity and trade barriers. By varying the parameter a, we can gauge the impact of profit-bias on the equilibrium patent protection (ω_i^E). As expected, a higher value of a is associated with a higher level of equilibrium protection. For example, for the case $\frac{\lambda}{\epsilon-1} = 1$, $\epsilon = 1.5$, $t = 0$, ω_{US}^E raises from 0.341 when $a = 0.000315$ to 0.373 when $a = 1.3333$. For the counterpart case of $\frac{\lambda}{\epsilon-1} = 1.049$ keeping ϵ and t unchanged, ω_{US}^E raises from 0.39 to 0.423. The effect of profit-bias is more significant at higher values of demand elasticity (say, $\epsilon = 9.28$) or higher trade barrier (t=0.5).

By comparing the levels of Nash patent protection for different values of $\frac{\lambda}{\epsilon-1}$, we note a positive association between the protection level and the shape parameter $\frac{\lambda}{\epsilon-1}$ of the firm profit distribution. For example, for the case with $\epsilon = 5$, $a = 1.33$ and $t = 0$ presented in Table 2, lowering $\frac{\lambda}{\epsilon-1}$ from 1.049 to 1 (meaning the presence of more large firms in the distribution) leads to a reduction in ω_{US}^E from 0.588 to 0.529. The most dramatic effect on θ^i is an increase of $\frac{\lambda}{\epsilon-1}$ from 1.0 to 1.049, leading to a decrease of θ^i from 1 to 0.742 in Austria, the smallest market in the sample.

In the same vein, we can explore the effect of the variable trade cost by raising it from $t = 0$ to $t = 0.5$ while holding other parameters constant. For example, from Table 2, we find that a higher t leads to lower probabilities of exploiting an invention in each country (θ^i). For example, when $\epsilon = 5$, $\frac{\lambda}{\epsilon-1} = 1.049$, a=1.333, an increase of t from 0 to 0.5 leads to a decrease in θ^{US} from 0.915 to 0.862. However, the effects of t on ω_i^E is relatively small compared with those of the other two channels (profit-bias and firm heterogeneity).[17]

[17] As an additional robustness check, for ϵ=5, $\lambda/(\epsilon-1)$=1.049, t =1, we find that the largest value of a that would sustain the sufficient condition for under-protection is a=13, which is a huge number and cannot possibly be exceeded in practice. Furthermore, the largest value of a that would sustain no global over-protection of IPR under harmonization with the maximum Nash IPR level is a=8, which again is unlikely to be exceeded in practice.

Estimation results indicate that θ^i_{EX} varies across countries, but never exceed 0.2 under various sensitivity tests, while the values of θ^i_{FDI} for different countries are all below 0.04. The table below presents the values of θ^i_{EX} and θ^i_{FDI} for the case a=1.3333, $\epsilon = 9.28$, $\lambda/(\epsilon - 1) = 1.049$, $t = 0.5$:

country	θ^i_{EX}	θ^i_{FDI}	θ^i	country	θ^i_{EX}	θ^i_{FDI}	θ^i
US	0.150	0.030	0.851	India	0.011	0.002	0.752
Japan	0.150	0.030	0.851	S. Korea	0.049	0.010	0.808
Germany	0.097	0.019	0.834	Netherlands	0.048	0.010	0.807
France	0.073	0.015	0.823	Australia	0.007	0.001	0.735
UK	0.065	0.013	0.819	Mexico	0.015	0.003	0.763
China	0.041	0.008	0.801	Argentina	0.017	0.003	0.764
Italy	0.052	0.010	0.810	Switzerland	0.015	0.016	0.826
Brazil	0.007	0.001	0.735	Belgium	0.079	0.006	0.791
Spain	0.008	0.002	0.743	Sweden	0.031	0.012	0.815
Canada	0.066	0.013	0.819	Austria	0.008	0.002	0.742

It should be noted that if we ignored FDI / licensing, we would have severely overestimated the barriers to exploit an invention internationally. For example, in the case of the US firms selling to Japan, if the iceberg trade cost is t=0.5, a=1.333, $\frac{\lambda}{\epsilon-1}$ =1.049, $\epsilon = 9.28$, and if we consider the fact that 15% of US firms sell to Japan and assume that they do not do FDI/licensing, then the estimated θ^{Japan} is 0.032 [i.e. $(1+0.5)^{-9.28+1} \cdot (0.15)^{1-\frac{1}{1.049}}$]. If we take into account the fact that 1/5 of those firms that sell to Japan (i.e. 3% of all US firms) in fact carry out FDI/licensing, then the estimated θ^{Japan} is 0.851 [i.e. $(1+0.5)^{-9.28+1} \cdot (0.15)^{1-\frac{1}{1.049}} + [1-(1+0.5)^{-9.28+1}](0.03)^{1-\frac{1}{1.049}}$]. That is a huge difference. The errors in the estimation of θ^i of other countries would be equally large. In fact, by omitting FDI / licensing, we would have concluded that the sufficient condition for under-protection would not be satisfied, as the magnitudes of the calibrated cross-border externalities would be really small. As the error becomes more serious as $\frac{\lambda}{\epsilon-1}$ gets closer to one, the empirical fact that firm revenues follow a fat-tailed distribution implies that it is really important to include FDI as an alternative channel of exploitation of an invention internationally (besides exporting) in any empirical work.[18]

[18] As a final note to this section, we recognize that some people may argue that the globally optimal combination of strengths of national patent protection should take into account the politically-augmented objective function of each national government, as these functions reflect the preferences of each government, which represents each country in international negotiations. If maximizing the sum of the politically-augmented objective functions is the goal of international coordination, then one simply need to remove the term $+\pi a \phi_i$ from the

5.2 Harmonization with the most protective country

Our analysis in the previous section indicates that under-protection of IPR will be resulted without international coordination. A natural question to ask is whether the current form of international coordination mandated by TRIPS is over-protective from a global welfare perspective. Adopting the views of Reichman (1995) and Lai and Qiu (2003), we assume that TRIPS requires all countries in the world to harmonize their IPR standards with the pre-TRIPS standards of the most protective country.[19] We then seek to answer the above question based on this characterization of TRIPS.

Suppose we sum up all the J first order conditions (15) and impose the restriction $\Omega_j = \Omega^*$ $\forall j \in \mathcal{N}$ on this equation. The solution of Ω^* will then yield the harmonized patent strength that is globally efficient. Suppose country k is the most protective country in equilibrium, i.e. $\Omega_k^E = \max\{\Omega_j^E \big| j \in \mathcal{N}\}$, where Ω_j^E is the equilibrium value of Ω_j. Then, $\Omega_k^E < \Omega^*$ is the necessary and sufficient condition that there is no over-protection of patent rights even if all countries harmonize their IPR standards with the most protective country in the world. We have already solved for Ω_k^E, which is Ω_{US}^E, in the earlier section. Adopting the same set of parametric values and employing the same set of countries as in the previous section, we compute the values of Ω^*. The values of Ω^* under different parameter values are provided in the last rows of Table 2. As the values of Ω^* are all close to 1, which exceeds the equilibrium protection strengths of all countries including the US in all cases, we conclude that $\Omega_{US}^E < \Omega^*$. This means that there is no global over-protection of IPR resulting from TRIPS.

Therefore, we conclude that the distribution of innovative capability among countries is not too skewed so that requiring all countries to harmonize their patent standards with that of the most protective (and most innovative) country in Nash equilibrium (i.e. the US) does not lead

marginal cost of the aggregate objective function (represented by the LHS of equation (15)). In this case, it is clear that there is always under-protection of patents in each country, as the marginal global cost is lower than the marginal national cost while the marginal global benefit is higher than the marginal national benefit. There are unambiguous positive cross-border externalities as the increases in the foreign firm profits and foreign consumer surplus due to induced innovations are not taken into account when Ω_i increases, just like in the basic G-L model. The spillovers are smaller in this extended model due to the presence of trade barriers.

[19] If one examines the Ginarte-Park patent rights index for the periods 1960-1990, 1995, 2000 and 2005 (refer to Park 2005), one sees that the most protective country before TRIPS (i.e. 1960-1990) was the US, whose index was 4.14. By 2005, all developed or newly industrialized economies would have already adopted the patent standard required by TRIPS. What is the patent right index for countries that adopt the minimum requirement mandated by TRIPS? It turned out that it is about 4.1 (e.g. Israel 4.13, Australia 4.17, New Zealand 4.01, Norway 4.17). So harmonization with the pre-TRIPS standard of the US is more or less what the TRIPS mandated.

to over-protection of patent rights from the global welfare point of view.[20] The situation in a two-country case is shown in Figure 1. It shows that global harmonization with the North's pre-TRIPS standard is a movement from point E to point E'. As E' is still inside the frontier GG, global welfare increases from E to E'. The North gains more than the South loses in this global IPR harmonization scheme, and global welfare increases. Taken together, the two results in this section indicate that TRIPS is globally welfare-improving.

6 Conclusion

On the theoretical front, we extend the Grossman and Lai (2004) model to analyze the interaction among innovation, firm heterogeneity, exporting/FDI and patenting in a unified framework. On the empirical front, we find that there is under-protection of global patent rights in the non-cooperative equilibrium given the estimates of the profit-bias parameter in the political economy literature and the estimated magnitudes of trade barriers. Our conclusion to this question is robust to alternative parameter values obtained in the literature. This is because, despite the existence of trade barriers, the free-rider problem becomes very serious when there is a large number of country-players in the patent-setting game. The empirical fact that firm revenues follow a fat-tailed distribution mitigates trade and FDI barriers a great deal, sustaining a high level of cross-border patenting externalities despite the fact that only a small fraction of firms sell overseas (no more than say 15%) and an even small fraction of firms carry out FDI (no more than say 3%). In our model, whether or not the patent policy harmonization scheme as mandated by TRIPS is over-protective depends on the magnitudes of the trade barriers and profit-bias, as well as the distribution of innovative capability and the distribution of market size among the countries in the world. Calibrating the model, we find that requiring all countries to harmonize their patent strengths with the equilibrium strength of the most protective country does not lead to global over-protection of IPR. This is because the distribution of innovative capability among countries is not too skewed as to overcome the free-rider effect. If such a scheme captures what the TRIPS has done, then there is no evidence that TRIPS leads to global over-protection of patent rights. In other words, TRIPS is globally welfare-improving.

In our calibration exercise, we find that omitting FDI / licensing as an alternative channel

[20] In a longer working paper version of this paper, we prove a proposition that implies that it is less likely for there to be over-protection when the distribution of innovative capability among countries is not too skewed. This makes sense as harmonization with the standard of the most innovative (and protective) country becomes more onerous for the other countries if the most protective country is a lot more protective than the rest of the countries.

of exploiting an invention internationally (besides exporting) can severely over-estimate the barriers for firms to sell overseas. Therefore, it is important to include both exporting and FDI in any model that attempts to explain international exploitation of technology.

The theoretical framework can possibly be exploited further to analyze empirically the relationship between innovation, trade barriers, market size, patent protection, and trade flows of patent-sensitive goods among countries. This is left to future research.

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Appendix

A Mean values of profit and consumer surplus

Define the unconditional means of the monopoly profit, the competitive consumer surplus and consumer surplus under monopoly, per consumer, as

$$\pi = \int \widetilde{\pi}(c)\, dF(c)\,; \quad C_c = \int \widetilde{C}_c(c)\, dF(c)\,; \quad \text{and} \quad C_m = \int \widetilde{C}_m(c)\, dF(c)$$

where c is the unit cost of production. $\widetilde{\pi}(c)$, $\widetilde{C}_c(c)$ and $\widetilde{C}_m(c)$ are monopoly profit, the competitive consumer surplus and consumer surplus under monopoly, respectively, expressed as functions of c. Define productivity $z = 1/c$. We assume that z follows a Pareto distribution. Therefore, $F(c) = (bc)^{\lambda}$.

Recall that the demand of a typical consumer is $x = Ap^{-\epsilon}$ (where $\epsilon > 1$). It can be easily shown that

$$\widetilde{C}_c = A\left(\frac{1}{\epsilon-1}\right) c^{-\epsilon+1} \text{ where } \Pr(c \leq s) = (bs)^{\lambda}\,. \tag{18}$$

Therefore, the unconditional mean of the competitive consumer surplus is given by:

$$\begin{aligned} C_c &= \int_0^{\frac{1}{b}} A\left(\frac{1}{\epsilon-1}\right) c^{-\epsilon+1} b^{\lambda}\lambda c^{\lambda-1} dc \\ &= A\left(\frac{1}{\epsilon-1}\right)\lambda\left(\frac{1}{1-\epsilon+\lambda}\right) b^{\epsilon-1}. \end{aligned}$$

Similarly,

$$\widetilde{\pi} = \widetilde{C}_m = A\left(\frac{1}{\epsilon-1}\right)\Lambda c^{-\epsilon+1} \quad \text{where} \quad \Lambda \equiv C_m/C_c \tag{19}$$

$$\text{and so} \quad \pi = C_m = A\left(\frac{1}{\epsilon-1}\right)\Lambda\left(\frac{\lambda}{1-\epsilon+\lambda}\right) b^{\epsilon-1}.$$

B The distribution of firm profits

As Axtell (*Science, 2001*) and other empirical work suggest, firm size follows a Pareto Distribution $P(s,\alpha)$, where α is very close to 1. Therefore, it is natural to assume that firm productivity follows a Pareto Distribution $P(b,\lambda)$:

$$\Pr\left(\frac{1}{c} < x\right) = 1 - \left(\frac{b}{x}\right)^{\lambda}, \text{ where } x \in [b, \infty)$$

which is equivalent to $\Pr(c < z) = \Pr(\frac{1}{c} > \frac{1}{z}) = (bz)^{\lambda}$, where $z \in [0, \frac{1}{b}]$.

Since $\widetilde{\pi} = A\left(\frac{1}{\epsilon-1}\right)\Lambda c^{-\epsilon+1}$, we have, $\forall s$

$$\begin{aligned}\Pr(\widetilde{\pi} &< s) = \Pr\left[A\left(\frac{\Lambda}{\epsilon-1}\right)c^{-\epsilon+1} < s\right] \\ &= \Pr\left[\frac{1}{c} < \left(\frac{(\epsilon-1)\,s}{A\Lambda}\right)^{\frac{1}{\epsilon-1}}\right] \\ &= 1-\left(\frac{A\Lambda b^{\epsilon-1}}{\epsilon-1}\right)^{\frac{\lambda}{\epsilon-1}}\cdot s^{-\frac{\lambda}{\epsilon-1}}\end{aligned} \tag{20}$$

This implies that, $\widetilde{\pi}$ follows a Pareto Distribution $P(\pi_{\min}, \frac{\lambda}{\epsilon-1})$, where $\pi_{\min} = \frac{A\Lambda b^{\epsilon-1}}{\epsilon-1}$, represents the minimum firm profit per consumer.

According to Axtell (2001), the index $\frac{\lambda}{\epsilon-1}$ should be very close to 1. Using US Census Bureau data on the firm size of the entire population of tax-paying firms in the US, the number is around 1.05, and this number is also adopted by other researchers.

C Fixed cost of exporting and probability of exporting

A firm will carry out FDI in country k iff

$$\begin{aligned}&\widetilde{\pi}(c)\,M_k\Omega_k - F_{FDI} \geq y\widetilde{\pi}(c)\,M_k\Omega_k - F_{EX} \quad \text{for a firm with unit cost } c \\ \Leftrightarrow\quad & F_{FDI} = (1-y)\,\widetilde{\pi}\left(c_{FDI}^k\right)M_k\Omega_k + F_{EX}\end{aligned} \tag{21}$$

where c_{FDI}^k is the critical c for FDI to country k. A firm will export to country k iff

$$\begin{aligned}&y\widetilde{\pi}(c)\,M_k\Omega_k - F_{EX} \geq 0 \quad \text{for a firm with unit cost } c \\ \Leftrightarrow\quad & F_{EX} = y\widetilde{\pi}\left(c_{EX}^k\right)M_k\Omega_k \quad \text{where } c_{EX}^k \text{ is the critical } c \text{ for exporting to country } k.\end{aligned} \tag{22}$$

From the last two equation, we have

$$F_{FDI} = (1-y)\,\widetilde{\pi}\left(c_{FDI}^k\right)M_k\Omega_k + y\widetilde{\pi}\left(c_{EX}^k\right)M_k\Omega_k\ . \tag{23}$$

We assume that $\frac{F_{EX}}{F_{FDI}} < y$ so that the firm that carries out FDI in a country always has the option of exporting to that country but chooses not to do so. In other words, the cutoff market-size-adjusted profit for carrying out FDI is always higher than that for exporting to a country. See Figure 3.

<Figure 3 about here>

We further assume that even if a good is not sold in a foreign market, the innovator still obtains a patent there. Therefore, the good cannot be legally imitated in that market until the patent expires. (20) implies that

$$\begin{aligned}\Pr(\widetilde{\pi} &< s) = 1-\left(\frac{A\Lambda b^{\epsilon-1}}{\epsilon-1}\right)^{\frac{\lambda}{\epsilon-1}}\cdot s^{-\frac{\lambda}{\epsilon-1}} \\ \Longleftrightarrow\quad & \theta_{EX}^k = \Pr\left(\widetilde{\pi} > \widetilde{\pi}\left(c_{EX}^k\right)\right) = 1-\Pr\left(\widetilde{\pi} < \widetilde{\pi}\left(c_{EX}^k\right)\right) = \left[\frac{A\Lambda b^{\epsilon-1}}{\widetilde{\pi}\left(c_{EX}^k\right)(\epsilon-1)}\right]^{\frac{\lambda}{\epsilon-1}} \\ \Longleftrightarrow\quad & \widetilde{\pi}\left(c_{EX}^k\right) = \frac{A\Lambda b^{\epsilon-1}}{\epsilon-1}\left(\theta_{EX}^k\right)^{\frac{1-\epsilon}{\lambda}}\ .\end{aligned} \tag{24}$$

Similarly, we have

$$\widetilde{\pi}\left(c_{FDI}^{k}\right)=\frac{A\Lambda b^{\epsilon-1}}{\epsilon-1}\left(\theta_{FDI}^{k}\right)^{\frac{1-\epsilon}{\lambda}}. \tag{25}$$

Therefore, (22) and (24) implies

$$F_{EX}=\Gamma y M_k\Omega_k\Lambda\left(\theta_{EX}^{k}\right)^{\frac{1-\epsilon}{\lambda}} \quad \text{where } \Gamma\equiv\frac{Ab^{\epsilon-1}}{\epsilon-1}$$

and (23), (24) and (25) imply

$$F_{FDI}=\Gamma M_k\Omega_k\Lambda\left[(1-y)\left(\theta_{FDI}^{k}\right)^{\frac{1-\epsilon}{\lambda}}+y\left(\theta_{EX}^{k}\right)^{\frac{1-\epsilon}{\lambda}}\right].$$

D Value of a Patent

Following the equations in the last section, firm profit $\widetilde{\pi}=A\left(\frac{\Lambda}{\epsilon-1}\right)c^{-\epsilon+1}$ follows a Pareto distribution $P\left(\frac{A\Lambda b^{\epsilon-1}}{\epsilon-1},\frac{\lambda}{\varepsilon-1}\right)$. The cutoff cost of exporting to and doing FDI in country k, c_{EX}^{k} and c_{FDI}^{k} are determined by (19), (21) and (22). After solving for c_{EX}^{k} and c_{FDI}^{k}, it is clear that (1) All firms $c\in\left[0,\frac{1}{b}\right]$ will produce and sell domestically; (2) Firms with $c\in\left[c_{FDI}^{k},c_{EX}^{k}\right]$ will also export to (but do not do FDI in) country k, and get a profit $y\pi(c)$; (3) Firms with $c\in\left[0,c_{FDI}^{k}\right]$ will also do FDI in (but not export to) country k, and get a profit $\widetilde{\pi}(c)$.

Then, a firm in country i does not only sell domestically and gets an expected profit of

$$\pi=\int_0^{\frac{1}{b}}\widetilde{\pi}(c)dF(c)=A\left(\frac{1}{\epsilon-1}\right)\Lambda\left(\frac{\lambda}{1-\epsilon+\lambda}\right)b^{\epsilon-1}, \text{ where } F(c)=(bc)^{\lambda},$$

but also exports to (but not do FDI in) country k ($\neq i$), and gets an expected exporting profit of

$$\pi_{EX}^{k}=\int_{c_{FDI}^{k}}^{c_{EX}^{k}}y\pi(c)dF(c)=y\left(\frac{\lambda}{\lambda-\varepsilon+1}\right)\left(\frac{A\Lambda b^{\lambda}}{\epsilon-1}\right)\left[\left(c_{EX}^{k}\right)^{\lambda-\varepsilon+1}-\left(c_{FDI}^{k}\right)^{\lambda-\varepsilon+1}\right],$$

or do FDI in (but not export to) country k ($\neq i$), and gets an expected FDI profit of

$$\pi_{FDI}^{k}=\int_0^{c_{FDI}^{k}}\widetilde{\pi}(c)dF(c)=\left(\frac{\lambda}{\lambda-\varepsilon+1}\right)\left(\frac{A\Lambda b^{\lambda}}{\epsilon-1}\right)\left(c_{FDI}^{k}\right)^{\lambda-\varepsilon+1}.$$

Then, we can obtain the expected value of a patent for a firm in country i as:

$$v_i=\pi M_i\Omega_i+\sum_{k\neq i}\pi_k M_k\Omega_k-\sum_{k\neq i}\left[\left(\theta_{EX}^{k}-\theta_{FDI}^{k}\right)F_{EX}+\theta_{FDI}^{k}F_{FDI}\right],$$

$$\begin{aligned}\text{where}\quad \pi_k &= \pi_{EX}^{k}+\pi_{FDI}^{k}\\ &= \left(\frac{\lambda}{\lambda-\varepsilon+1}\right)\left(\frac{A\Lambda b^{\epsilon-1}}{\epsilon-1}\right)\left\{y\left[\left(\theta_{EX}^{k}\right)^{\frac{\lambda-\varepsilon+1}{\lambda}}-\left(\theta_{FDI}^{k}\right)^{\frac{\lambda-\varepsilon+1}{\lambda}}\right]+\left(\theta_{FDI}^{k}\right)^{\frac{\lambda-\varepsilon+1}{\lambda}}\right\}\\ &= \pi\theta^{k}\end{aligned}$$

$$\text{and}\quad C_m^{k}=C_{m,EX}^{k}+C_{m,FDI}^{k}=C_m\theta^{k}\quad \text{since } \widetilde{\pi}(c)=\widetilde{C}_m(c) \text{ for all } c.$$

$$\text{with} \quad \theta^k = y\left[\left(\theta^k_{EX}\right)^{\frac{\lambda-\varepsilon+1}{\lambda}} - \left(\theta^k_{FDI}\right)^{\frac{\lambda-\varepsilon+1}{\lambda}}\right] + \left(\theta^k_{FDI}\right)^{\frac{\lambda-\varepsilon+1}{\lambda}}$$

$$\text{and} \quad \theta^k_{EX} = \Pr\left(c < c^k_{EX}\right) = \left(b \cdot c^k_{EX}\right)^{\lambda},$$

$$\text{and} \quad \theta^k_{FDI} = \Pr\left(c < c^k_{FDI}\right) = \left(b \cdot c^k_{FDI}\right)^{\lambda}.$$

Therefore,

$$\begin{aligned}
v_i &= \pi M_i \Omega_i + \sum_{k\neq i} \pi_k M_k \Omega_k - \sum_{k\neq i}\left[\left(\theta^k_{EX} - \theta^k_{FDI}\right) F_{EX} + \theta^k_{FDI} F_{FDI}\right] \\
&= \pi M_i \Omega_i + \sum_{k\neq i} \pi M_k \Omega_k \theta^k \\
&\quad - \sum_{k\neq i}\left\{\left(\theta^k_{EX} - \theta^k_{FDI}\right)\Gamma y M_k \Omega_k \Lambda \left(\theta^k_{EX}\right)^{\frac{1-\epsilon}{\lambda}} + \theta^k_{FDI}\Gamma M_k \Omega_k \Lambda\left[(1-y)\left(\theta^k_{FDI}\right)^{\frac{1-\epsilon}{\lambda}} + y\left(\theta^k_{EX}\right)^{\frac{1-\epsilon}{\lambda}}\right]\right\} \\
&= \pi\left[M_i \Omega_i + \left(\frac{\epsilon - 1}{\lambda}\right)\sum_{k\neq i} M_k \Omega_k \theta^k\right]
\end{aligned}$$

E Proof of Proposition 1

Recall that the Nash equilibrium condition (12) is equivalent to $\frac{1}{M_i}\frac{\partial W_i(a)}{\partial \Omega_i} = 0$ while the global optimum condition (15) is equivalent to $\frac{1}{M_i}\frac{\partial W^w}{\partial \Omega_i} = 0$. We have established in Lemma 1 that a sufficient condition for under-protection in the Nash equilibrium is $\left(\sum_i \frac{1}{M_i}\frac{\partial W^w}{\partial \Omega_i}\right) > 0$ for all combinations of $\{\Omega_i\}_{i\in\mathcal{N}}$ that satisfy $\sum_i \frac{1}{M_i}\frac{\partial W_i(a)}{\partial \Omega_i} = 0$. From equation (15), we know this condition is equivalent to

$$\begin{aligned}
&\sum_i \left[\pi a \phi_i - \theta^i \pi \left(\sum_{j\neq i}\phi_j\right)\right] \\
<\;& \sum_i \left[\sum_{k\neq i}\left(\gamma \frac{\phi_i}{v_i}\pi M_k f'_k + \sum_{j\neq k,i}\gamma\frac{\phi_j}{v_j}\theta^i \pi M_k f'_k\right) + \sum_{k\neq i}\gamma\frac{\phi_k}{v_k}\theta^i \pi M_k f_k\right] \qquad (26)
\end{aligned}$$

for all combinations of $\{\Omega_i\}_{i\in\mathcal{N}}$ that satisfy $\sum_i \frac{1}{M_i}\frac{\partial W_i(a)}{\partial \Omega_i} = 0$.

The RHS of (26) is greater than zero, as there are positive cross-border externalities as a country strengthens its patent protection. Therefore, a sufficient condition for (26) to hold is

$$\sum_i \left[a\phi_i - \theta^i\left(\sum_{j\neq i}\phi_j\right)\right] < 0,$$

and a sufficient condition of which is

$$a - \sum_{i\neq \max}\theta^i < 0$$

where $\theta^{\max}$ is the largest θ^i among all countries. This gives condition (17). ■

F Data for Market Size (M) and Innovative Capability (ϕ)

The market size variable (M_i) is proxied by the natural logarithm of the average dollar value of consumption (or use) of patent-sensitive goods per year by country i over the years 1996-1999 (estimated by Lai, Wong and Yan, 2007). The innovative capability variable (ϕ_i) is proxied by the average number of patents granted to the resident of country i by the US patent office per year over the years 1996-1999 (obtained from the WIPO website) divided by population. However, to adjust for home-bias of the US data, we calculate the US innovative capability as the mean of an upper bound and a lower bound. The upper bound is given by the yearly average of the actual number of patents granted to US residents by the US patent office, P_{US}^{US}, where P_i^j denotes the number of patents granted to residents of country i by country j. This is an upper bound because it probably over-states the innovative capability of the US because even relatively trivial inventions might be patented in the US by US residents as the cost of patenting and subsequent working of the patents by domestic residents is relatively low. This is the home bias effect. The lower bound estimate is obtained by the formula

$$\widetilde{P_{US}^{US}} = \frac{P_{US}^{EPO}}{P_{Japan}^{EPO}} \times P_{Japan}^{US}.$$

The idea is that the American capability to obtain patents relative to that of Japan in Europe is approximately equal to the American capability to obtain patents relative to that of Japan in the US. Comparison with Japan is chosen because its innovative capability is comparable to that of the US while other countries are much further behind. The reason for choosing patents awarded in Europe is because European countries have a longer tradition of patent protection and have patent systems similar to that of the US. Japan, on the other hand, has a more liberal patent system with narrower protection those in the US and Europe. Therefore, calibration with the Japanese patent counts is not done. The estimate $\widetilde{P_{US}^{US}}$ is considered a lower bound of US innovative capability as some useful American innovations are not patented overseas perhaps because they are relatively less significant (though may be still useful). This is just the opposite of the home bias effect.

The estimated innovative capability of the US is therefore calculated as

$$\widehat{\phi_{US}} = \frac{\widetilde{P_{US}^{US}} + P_{US}^{US}}{2}$$

After taking the above into account, we obtain Table 1, which shows the patent counts and market sizes of the twenty most innovative countries.

	Innovative capacity (ϕ)	Market size (M)
US[2]	187.83	9.25
Japan	214.25	9.07
Germany	98.32	8.75
France	56.76	8.57
UK	52.08	8.45
China	0.06	8.45
Italy	24.24	8.43
Brazil	0.43	8.31
Spain	5.07	8.19
Canada	89.80	8.17
India	0.07	8.15
South Korea	55.34	8.13
Netherlands	65.15	8.02
Australia	31.91	7.99
Mexico	0.57	7.97
Argentina	1.06	7.88
Switzerland	167.53	7.85
Belgium	57.50	7.83
Sweden	122.82	7.77
Austria	50.25	7.76
Total	1281.02	164.97

Table 1: Data on the Market Size of Patent-Sensitive Goods and Patent Counts

Note:

1. M is the logarithm of the average annual consumption (or absorption) of patent-sensitive goods in the country over the years 1996-1999
2. ϕ is the average number of patents granted to residents of the country per year by the US Patent Office over the years 1996-1999 divided by population of the country. The patent count of the US is adjusted for the home-bias effect discussed in Appendix F.

	Trade Cost (t)=0												Trade Cost (t)=0.5											
	ε =1.5				ε =5				ε =9.28				ε =1.5				ε = 5				ε =9.28			
	$\frac{\lambda}{\varepsilon-1}=1$		$\frac{\lambda}{\varepsilon-1}=1.049$		$\frac{\lambda}{\varepsilon-1}=1$		$\frac{\lambda}{\varepsilon-1}=1.049$		$\frac{\lambda}{\varepsilon-1}=1$		$\frac{\lambda}{\varepsilon-1}=1.049$		$\frac{\lambda}{\varepsilon-1}=1$		$\frac{\lambda}{\varepsilon-1}=1.049$		$\frac{\lambda}{\varepsilon-1}=1$		$\frac{\lambda}{\varepsilon-1}=1.049$		$\frac{\lambda}{\varepsilon-1}=1$		$\frac{\lambda}{\varepsilon-1}=1.049$	
	ω_i^E	θ^i	ω_i^E	θ^i	ω_i^E	θ^i	ω_i^E	θ^i	ω_i^E	θ^i	ω_i^E	θ^i	ω_i^E	θ^i	ω_i^E	θ^i	ω_i^E	θ^i	ω_i^E	θ^i	ω_i^E	θ^i	ω_i^E	θ^i
US	**0.373**	1	**0.423**	0.917	**0.529**	1	**0.588**	0.915	**0.561**	1	**0.621**	0.915	**0.373**	1	**0.424**	0.904	**0.520**	1	**0.579**	0.862	**0.550**	1	**0.607**	0.851
Japan	**0.367**	1	**0.418**	0.915	**0.520**	1	**0.597**	0.915	**0.550**	1	**0.633**	0.915	**0.367**	1	**0.419**	0.903	**0.529**	1	**0.589**	0.862	**0.561**	1	**0.620**	0.851
Germany	**0.285**	1	**0.318**	0.901	**0.368**	1	**0.418**	0.898	**0.384**	1	**0.439**	0.897	**0.285**	1	**0.318**	0.889	**0.368**	1	**0.409**	0.845	**0.384**	1	**0.425**	0.834
France	**0.246**	1	**0.267**	0.893	**0.298**	1	**0.331**	0.887	**0.307**	1	**0.344**	0.886	**0.246**	1	**0.266**	0.881	**0.298**	1	**0.321**	0.834	**0.307**	1	**0.331**	0.823
UK	**0.231**	1	**0.247**	0.889	**0.276**	1	**0.303**	0.882	**0.285**	1	**0.315**	0.881	**0.231**	1	**0.246**	0.877	**0.276**	1	**0.293**	0.830	**0.285**	1	**0.302**	0.819
China	**0.207**	1	**0.208**	0.881	**0.217**	1	**0.210**	0.867	**0.218**	1	**0.211**	0.864	**0.207**	1	**0.206**	0.869	**0.217**	1	**0.197**	0.814	**0.218**	1	**0.194**	0.801
Italy	**0.215**	1	**0.222**	0.884	**0.241**	1	**0.251**	0.874	**0.245**	1	**0.258**	0.873	**0.215**	1	**0.221**	0.872	**0.241**	1	**0.240**	0.822	**0.245**	1	**0.243**	0.810
Brazil	**0.189**	1	**0.181**	0.875	**0.196**	1	**0.168**	0.856	**0.196**	1	**0.035**	0.790	**0.189**	1	**0.180**	0.863	**0.196**	1	**0.154**	0.804	**0.196**	1	**0.034**	0.735
Spain	**0.176**	1	**0.161**	0.869	**0.182**	1	**0.040**	0.798	**0.182**	1	**0.044**	0.799	**0.176**	1	**0.159**	0.857	**0.182**	1	**0.040**	0.752	**0.182**	1	**0.043**	0.743
Canada	**0.214**	1	**0.228**	0.884	**0.279**	1	**0.308**	0.881	**0.291**	1	**0.325**	0.881	**0.214**	1	**0.228**	0.872	**0.279**	1	**0.302**	0.830	**0.291**	1	**0.316**	0.819
India	**0.170**	1	**0.148**	0.865	**0.171**	1	**0.052**	0.808	**0.170**	1	**0.056**	0.808	**0.170**	1	**0.147**	0.853	**0.171**	1	**0.052**	0.761	**0.170**	1	**0.056**	0.752
S. Korea	**0.192**	1	**0.193**	0.877	**0.232**	1	**0.239**	0.870	**0.239**	1	**0.250**	0.870	**0.192**	1	**0.193**	0.865	**0.232**	1	**0.232**	0.819	**0.239**	1	**0.240**	0.808
Netherlands	**0.182**	1	**0.180**	0.873	**0.226**	1	**0.231**	0.868	**0.234**	1	**0.244**	0.868	**0.182**	1	**0.180**	0.861	**0.226**	1	**0.226**	0.817	**0.234**	1	**0.235**	0.807
Australia	**0.163**	1	**0.142**	0.863	**0.182**	1	**0.037**	0.794	**0.185**	1	**0.038**	0.793	**0.163**	1	**0.141**	0.851	**0.182**	1	**0.035**	0.746	**0.185**	1	**0.036**	0.735
Mexico	**0.145**	1	**0.088**	0.842	**0.141**	1	**0.078**	0.823	**0.139**	1	**0.081**	0.822	**0.145**	1	**0.084**	0.829	**0.141**	1	**0.075**	0.774	**0.139**	1	**0.076**	0.763
Argentina	**0.133**	1	**0.064**	0.829	**0.127**	1	**0.082**	0.825	**0.125**	1	**0.084**	0.823	**0.133**	1	**0.064**	0.818	**0.127**	1	**0.078**	0.775	**0.125**	1	**0.079**	0.764
Switzerland	**0.208**	1	**0.231**	0.883	**0.323**	1	**0.367**	0.887	**0.346**	1	**0.395**	0.888	**0.208**	1	**0.232**	0.871	**0.323**	1	**0.365**	0.836	**0.346**	1	**0.390**	0.826
Belgium	**0.153**	1	**0.130**	0.858	**0.187**	1	**0.158**	0.851	**0.193**	1	**0.167**	0.851	**0.153**	1	**0.130**	0.847	**0.187**	1	**0.155**	0.802	**0.193**	1	**0.161**	0.791
Sweden	**0.177**	1	**0.181**	0.872	**0.257**	1	**0.280**	0.875	**0.273**	1	**0.302**	0.876	**0.177**	1	**0.182**	0.860	**0.257**	1	**0.278**	0.825	**0.273**	1	**0.297**	0.815
Austria	**0.140**	1	**0.094**	0.844	**0.166**	1	**0.049**	0.804	**0.170**	1	**0.048**	0.801	**0.140**	1	**0.094**	0.833	**0.166**	1	**0.045**	0.754	**0.170**	1	**0.043**	0.742
Harmonized global optimum	ω^* =1		ω^* =1		ω^* =1		ω^* =1		ω^* =1		ω^* =1		ω^* =1		ω^* =1		ω^* =1		ω^* =1		ω^* =1		ω^* =1	

Table 2: Nash Equilibrium and Harmonized Global Optimum (a=1.333)

Note:

1. ω_i^E denotes the patent protection of country i in Nash equilibrium. θ^i is defined as $y(\theta_{EX}^i)^{\frac{1-\varepsilon+\lambda}{\lambda}} + (1-y)(\theta_{FDI}^i)^{\frac{1-\varepsilon+\lambda}{\lambda}}$, where θ_{EX}^i and θ_{FDI}^i represent the probabilities of a foreign firm selling to and carrying out FDI in country *i* respectively. ω^* denotes the globally optimal level of harmonized patent protection .
2. ε refers to the price elasticity of demand of a typical consumer. The value of ε =5 is obtained from Lai, Wong and Yan (2007) and by putting together the findings of Axtell (2001) and Luttmer (2007) that the shape parameter of the Pareto distribution ($\frac{\lambda}{\varepsilon-1}$) is close to but larger than 1 and the finding of Simonovska (2011) that λ is approximately 4. The alternative value of ε =9.28 is obtained based on $\frac{\lambda}{\varepsilon-1} \approx 1$ and the finding of Eaton and Kortum (2002) that λ is approximately 8.28.
3. $\frac{\lambda}{\varepsilon-1}$ refers to the shape parameter of the distribution of firm revenues. Based on the data on US's firm size distributions in 1988-1997, Axtell (2001) obtain that $\frac{\lambda}{\varepsilon-1}$ is close to and larger than 1. A recent study by Luttmer (2007) finds that the shape parameter is also close to but larger than 1. We perform robustness check on $\frac{\lambda}{\varepsilon-1}$ by setting its upper end to 1.049.
4. "1+a" is the weight a government puts on domestic profits when a weight of one is put on domestic consumer surplus in its objective function. The parameter "a" measures the profit-bias of governments. It ranges from 0.000315 to 1.3333 in the literature (Goldberg and Maggi, 1999; Gawande et al., 2000; Mitra et al., 2002; Eicher and Osang, 2002; McCalman, 2004 and Mitra et al., 2005). Since a=1.3333 gives the most conservative case that makes us hardest to reach the under-proetction conclusion, we only present this case here. Lower values of "a" yield an even larger degree of under-protection in Nash equilibrium.

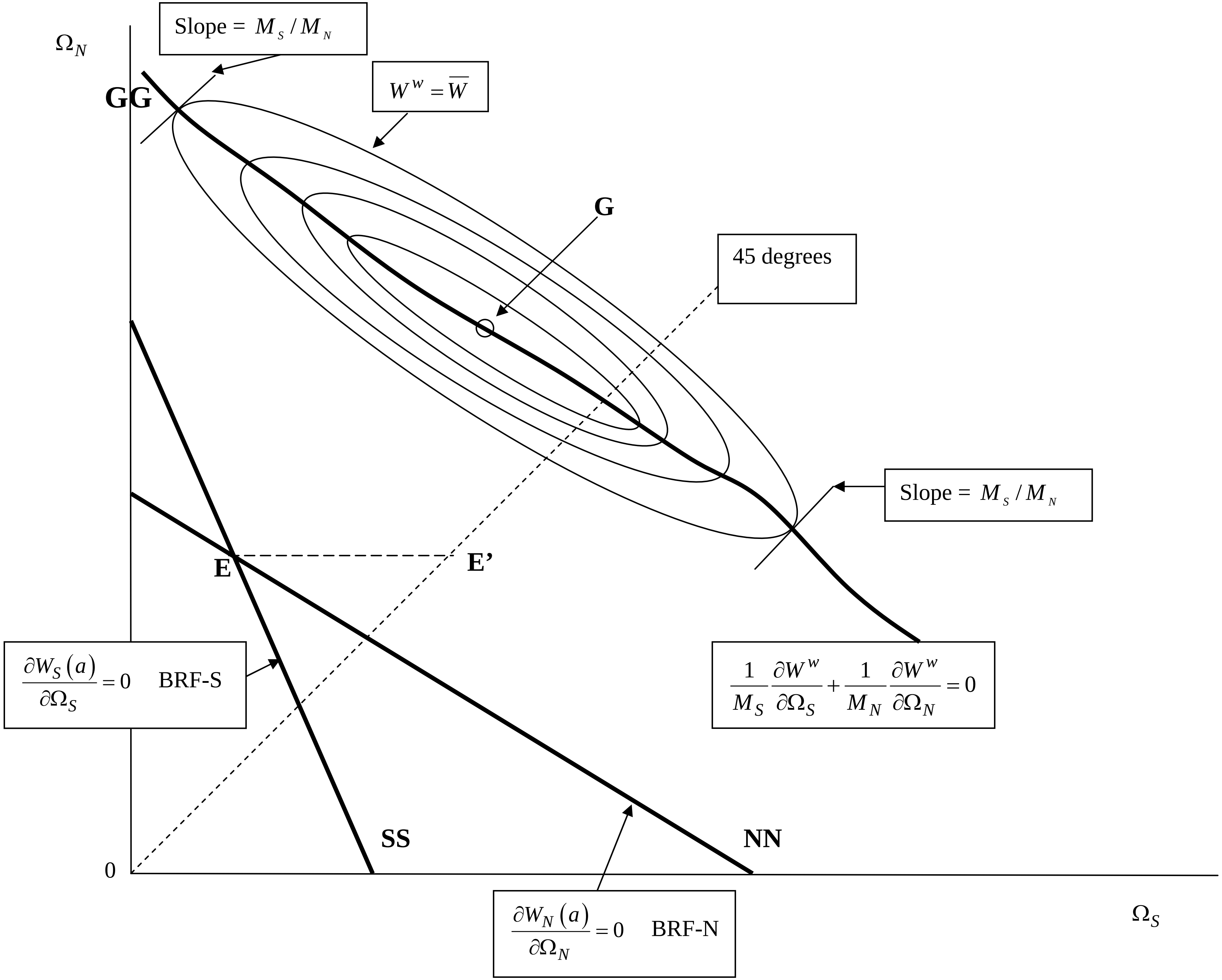

Figure 1: Relationship between Nash Equilibrium E and Global Optimum G.

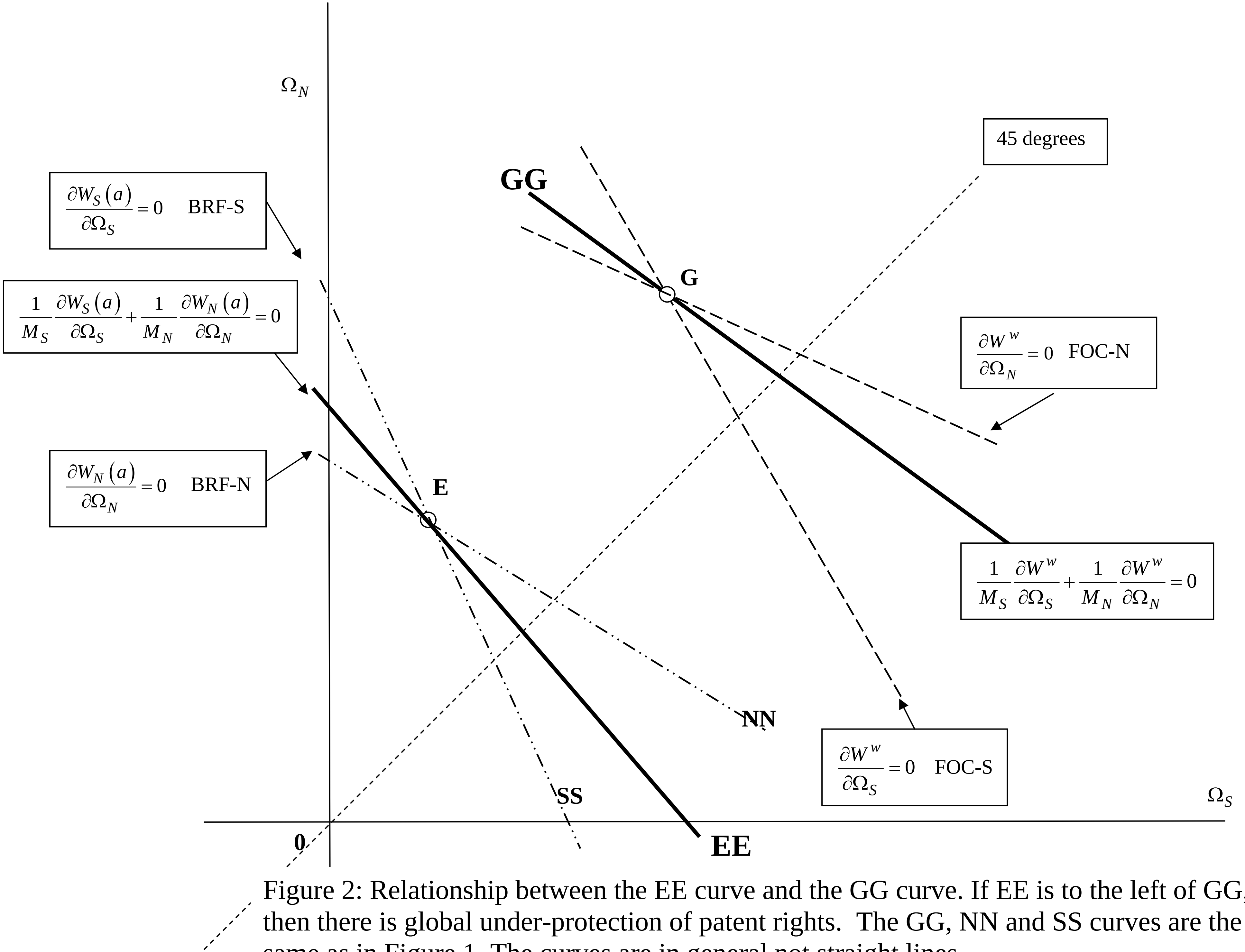

Figure 2: Relationship between the EE curve and the GG curve. If EE is to the left of GG, then there is global under-protection of patent rights. The GG, NN and SS curves are the same as in Figure 1. The curves are in general not straight lines.

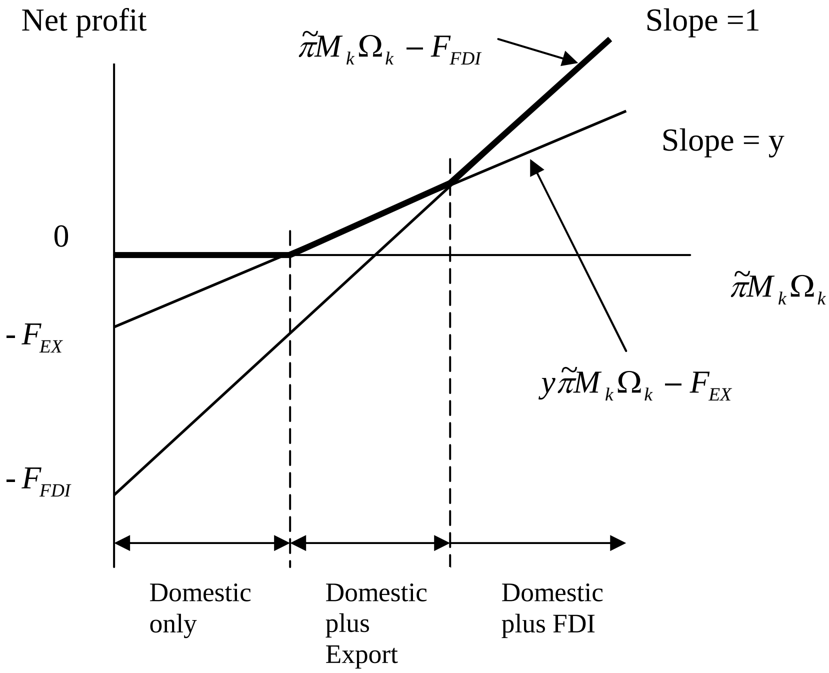

Figure 3: A Foreign Firm's Decision Concerning Exporting to and Carrying out FDI in Country k.

Tables 2A-2F are not for publication

	Price Elasticity of Demand (ε)=1.5 and Trade Cost (t)=0																	
	a=0.000315						a=1						a=1.3333					
	$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049				$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049				$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049			
	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i
US	**0.341**	1	**0.390**	0.158	0.032	0.918	**0.365**	1	**0.415**	0.156	0.031	0.917	**0.373**	1	**0.423**	0.155	0.031	0.917
Japan	**0.328**	1	**0.377**	0.150	0.030	0.915	**0.357**	1	**0.408**	0.150	0.030	0.915	**0.367**	1	**0.418**	0.150	0.030	0.915
Germany	**0.274**	1	**0.305**	0.116	0.023	0.904	**0.282**	1	**0.315**	0.110	0.022	0.902	**0.285**	1	**0.318**	0.109	0.022	0.901
France	**0.245**	1	**0.265**	0.098	0.020	0.897	**0.246**	1	**0.267**	0.090	0.018	0.894	**0.246**	1	**0.267**	0.088	0.018	0.893
UK	**0.231**	1	**0.246**	0.089	0.018	0.893	**0.231**	1	**0.247**	0.082	0.016	0.890	**0.231**	1	**0.247**	0.080	0.016	0.889
China	**0.221**	1	**0.225**	0.081	0.016	0.889	**0.211**	1	**0.213**	0.070	0.014	0.883	**0.207**	1	**0.208**	0.067	0.013	0.881
Italy	**0.223**	1	**0.231**	0.083	0.017	0.890	**0.217**	1	**0.225**	0.074	0.015	0.886	**0.215**	1	**0.222**	0.072	0.014	0.884
Brazil	**0.203**	1	**0.200**	0.070	0.014	0.883	**0.193**	1	**0.186**	0.060	0.012	0.877	**0.189**	1	**0.181**	0.057	0.011	0.875
Spain	**0.189**	1	**0.179**	0.062	0.012	0.878	**0.180**	1	**0.166**	0.052	0.010	0.871	**0.176**	1	**0.161**	0.049	0.010	0.869
Canada	**0.204**	1	**0.215**	0.074	0.015	0.886	**0.211**	1	**0.225**	0.072	0.014	0.884	**0.214**	1	**0.228**	0.071	0.014	0.884
India	**0.184**	1	**0.170**	0.058	0.012	0.876	**0.173**	1	**0.154**	0.048	0.010	0.868	**0.170**	1	**0.148**	0.045	0.009	0.865
South Korea	**0.191**	1	**0.192**	0.066	0.013	0.881	**0.192**	1	**0.193**	0.061	0.012	0.878	**0.192**	1	**0.193**	0.060	0.012	0.877
Netherlands	**0.179**	1	**0.174**	0.059	0.012	0.876	**0.181**	1	**0.179**	0.056	0.011	0.874	**0.182**	1	**0.180**	0.055	0.011	0.873
Australia	**0.169**	1	**0.150**	0.050	0.010	0.869	**0.164**	1	**0.144**	0.044	0.009	0.864	**0.163**	1	**0.142**	0.042	0.008	0.863
Mexico	**0.159**	1	**0.124**	0.041	0.008	0.861	**0.148**	1	**0.100**	0.030	0.006	0.849	**0.145**	1	**0.088**	0.025	0.005	0.842
Argentina	**0.148**	1	**0.094**	0.030	0.006	0.849	**0.137**	1	**0.064**	0.019	0.004	0.830	**0.133**	1	**0.064**	0.018	0.004	0.829
Switzerland	**0.177**	1	**0.189**	0.062	0.012	0.879	**0.200**	1	**0.221**	0.068	0.014	0.882	**0.208**	1	**0.231**	0.069	0.014	0.883
Belgium	**0.152**	1	**0.126**	0.041	0.008	0.861	**0.153**	1	**0.129**	0.038	0.008	0.859	**0.153**	1	**0.130**	0.038	0.008	0.858
Sweden	**0.157**	1	**0.151**	0.049	0.010	0.868	**0.172**	1	**0.174**	0.052	0.010	0.871	**0.177**	1	**0.181**	0.053	0.011	0.872
Austria	**0.140**	1	**0.095**	0.030	0.006	0.849	**0.140**	1	**0.095**	0.028	0.006	0.846	**0.140**	1	**0.094**	0.027	0.005	0.844
Harmonized global optimum	ω^* = 1		ω^* = 1				ω^* = 1		ω^* = 1				ω^* = 1		ω^* = 1			

Table 2A: Nash Equilibrium and Harmonized Global Optimum
When Price Elasticity of Demand ε=1.5 and Trade Cost t=0

Note:

1. ω_i^E denotes the patent protection of country i under non-cooperative Nash equilibrium. θ_{EX}^i and θ_{FDI}^i represent the probabilities of a foreign firm selling to and carrying out FDI in country *i* respectively. θ^i is defined as $y(\theta_{EX}^i)^{\frac{1-\varepsilon+\lambda}{\lambda}} + (1-y)(\theta_{FDI}^i)^{\frac{1-\varepsilon+\lambda}{\lambda}}$. ω^* denotes the globally optimal level of harmonized patent protection .

2. ε refers to the price elasticity of demand of a typical consumer. The value of ε=5 is obtained from Lai, Wong and Yan (2007) and by putting together the findings of Axtell (2001) and Luttmer (2007) that the scale parameter of the Pareto distribution ($\frac{\lambda}{\varepsilon - 1}$) is close to but larger than 1 and the finding of Simonovska (2011) that λ is approximately 4. The alternative value of ε=9.28 is obtained based on $\frac{\lambda}{\varepsilon - 1} \approx 1$ and the finding of Eaton and Kortum (2002) that λ is approximately 8.28.
3. $\frac{\lambda}{\varepsilon - 1}$ refers to the shape parameter of the distribution of firm revenues. Based on the data on US's firm size distributions in 1988-1997, Axtell (2001) obtain that $\frac{\lambda}{\varepsilon - 1}$ is close to but larger than 1. A recent study by Luttmer (2007) finds that the shape parameter is also close to but larger than 1. We perform robustness check on $\frac{\lambda}{\varepsilon - 1}$ by setting its upper end to 1.049.
4. "1+a" is the weight a government puts on domestic profits when a weight of one is put on domestic consumer surplus in its objective function. The parameter "a" measures the profit-bias of governments. It ranges from 0.000315 to 1.3333 in the literature (Goldberg and Maggi, 1999; Gawande et al., 2000; Mitra et al., 2002; Eicher and Osang, 2002; McCalman, 2004 and Mitra et al., 2005).

	Price Elasticity of Demand (ε)=5 and Trade Cost (t)=0																	
	a=0.000315						a=1						a=1.3333					
	$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049				$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049				$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049			
	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i
US	**0.440**	1	**0.504**	0.156	0.031	0.917	**0.504**	1	**0.564**	0.152	0.030	0.916	**0.529**	1	**0.588**	0.151	0.030	0.915
Japan	**0.430**	1	**0.496**	0.150	0.030	0.915	**0.500**	1	**0.568**	0.150	0.030	0.915	**0.520**	1	**0.597**	0.150	0.030	0.915
Germany	**0.339**	1	**0.380**	0.109	0.022	0.902	**0.361**	1	**0.404**	0.101	0.020	0.898	**0.368**	1	**0.418**	0.099	0.020	0.898
France	**0.295**	1	**0.319**	0.089	0.018	0.893	**0.297**	1	**0.323**	0.078	0.016	0.888	**0.298**	1	**0.331**	0.076	0.015	0.887
UK	**0.277**	1	**0.294**	0.081	0.016	0.889	**0.277**	1	**0.295**	0.070	0.014	0.883	**0.276**	1	**0.303**	0.068	0.014	0.882
China	**0.252**	1	**0.249**	0.068	0.014	0.882	**0.226**	1	**0.214**	0.050	0.010	0.869	**0.217**	1	**0.210**	0.047	0.009	0.867
Italy	**0.260**	1	**0.266**	0.072	0.014	0.884	**0.246**	1	**0.249**	0.058	0.012	0.876	**0.241**	1	**0.251**	0.056	0.011	0.874
Brazil	**0.231**	1	**0.215**	0.057	0.011	0.875	**0.205**	1	**0.173**	0.039	0.008	0.860	**0.196**	1	**0.168**	0.036	0.007	0.856
Spain	**0.215**	1	**0.188**	0.049	0.010	0.868	**0.191**	1	**0.138**	0.030	0.006	0.850	**0.182**	1	**0.040**	0.008	0.002	0.798
Canada	**0.254**	1	**0.268**	0.071	0.014	0.884	**0.272**	1	**0.293**	0.067	0.013	0.881	**0.279**	1	**0.308**	0.067	0.013	0.881
India	**0.208**	1	**0.171**	0.044	0.009	0.864	**0.181**	1	**0.053**	0.011	0.002	0.810	**0.171**	1	**0.052**	0.010	0.002	0.808
South Korea	**0.230**	1	**0.226**	0.059	0.012	0.876	**0.231**	1	**0.230**	0.052	0.010	0.871	**0.232**	1	**0.239**	0.051	0.010	0.870
Netherlands	**0.218**	1	**0.208**	0.053	0.011	0.872	**0.224**	1	**0.219**	0.049	0.010	0.868	**0.226**	1	**0.231**	0.049	0.010	0.868
Australia	**0.197**	1	**0.159**	0.040	0.008	0.860	**0.186**	1	**0.132**	0.028	0.006	0.847	**0.182**	1	**0.037**	0.007	0.001	0.794
Mexico	**0.178**	1	**0.076**	0.018	0.004	0.829	**0.150**	1	**0.081**	0.017	0.003	0.827	**0.141**	1	**0.078**	0.016	0.003	0.823
Argentina	**0.164**	1	**0.085**	0.020	0.004	0.834	**0.136**	1	**0.084**	0.017	0.003	0.827	**0.127**	1	**0.082**	0.016	0.003	0.825
Switzerland	**0.242**	1	**0.266**	0.067	0.013	0.881	**0.302**	1	**0.338**	0.075	0.015	0.886	**0.323**	1	**0.367**	0.077	0.015	0.887
Belgium	**0.184**	1	**0.136**	0.033	0.007	0.853	**0.186**	1	**0.142**	0.030	0.006	0.849	**0.187**	1	**0.158**	0.032	0.006	0.851
Sweden	**0.207**	1	**0.204**	0.050	0.010	0.870	**0.244**	1	**0.257**	0.055	0.011	0.874	**0.257**	1	**0.280**	0.058	0.012	0.875
Austria	**0.168**	1	**0.072**	0.017	0.003	0.826	**0.166**	1	**0.060**	0.012	0.002	0.814	**0.166**	1	**0.049**	0.009	0.002	0.804
Harmonized global optimum	ω^* = 1		ω^* = 1				ω^* = 1		ω^* = 1				ω^* = 1		ω^* = 1			

Table 2B: Nash Equilibrium and Harmonized Global Optimum
When Price Elasticity of Demand ε=5 and Trade Cost t=0

	Price Elasticity of Demand (ε)=9.28 and Trade Cost (t)=0																	
	a=0.000315						a=1						a=1.3333					
	$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049				$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049				$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049			
	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i
US	**0.458**	1	**0.517**	0.155	0.031	0.917	**0.533**	1	**0.597**	0.151	0.030	0.916	**0.561**	1	**0.621**	0.150	0.030	0.915
Japan	**0.450**	1	**0.524**	0.150	0.030	0.915	**0.526**	1	**0.604**	0.150	0.030	0.915	**0.550**	1	**0.633**	0.150	0.030	0.915
Germany	**0.351**	1	**0.393**	0.108	0.022	0.901	**0.375**	1	**0.427**	0.100	0.020	0.898	**0.384**	1	**0.439**	0.098	0.020	0.897
France	**0.304**	1	**0.328**	0.088	0.018	0.892	**0.306**	1	**0.340**	0.077	0.015	0.887	**0.307**	1	**0.344**	0.075	0.015	0.886
UK	**0.286**	1	**0.302**	0.079	0.016	0.888	**0.285**	1	**0.311**	0.069	0.014	0.883	**0.285**	1	**0.315**	0.067	0.013	0.881
China	**0.258**	1	**0.251**	0.065	0.013	0.880	**0.228**	1	**0.221**	0.049	0.010	0.868	**0.218**	1	**0.211**	0.044	0.009	0.864
Italy	**0.267**	1	**0.270**	0.070	0.014	0.883	**0.251**	1	**0.260**	0.057	0.011	0.875	**0.245**	1	**0.258**	0.054	0.011	0.873
Brazil	**0.236**	1	**0.215**	0.055	0.011	0.873	**0.206**	1	**0.179**	0.038	0.008	0.859	**0.196**	1	**0.035**	0.006	0.001	0.790
Spain	**0.219**	1	**0.186**	0.046	0.009	0.866	**0.192**	1	**0.042**	0.008	0.002	0.799	**0.182**	1	**0.044**	0.008	0.002	0.799
Canada	**0.263**	1	**0.277**	0.070	0.014	0.883	**0.284**	1	**0.313**	0.067	0.013	0.882	**0.291**	1	**0.325**	0.067	0.013	0.881
India	**0.211**	1	**0.167**	0.041	0.008	0.861	**0.181**	1	**0.053**	0.010	0.002	0.808	**0.170**	1	**0.056**	0.011	0.002	0.808
South Korea	**0.237**	1	**0.231**	0.057	0.011	0.875	**0.239**	1	**0.245**	0.052	0.010	0.871	**0.239**	1	**0.250**	0.051	0.010	0.870
Netherlands	**0.225**	1	**0.213**	0.052	0.010	0.871	**0.232**	1	**0.236**	0.049	0.010	0.869	**0.234**	1	**0.244**	0.048	0.010	0.868
Australia	**0.202**	1	**0.156**	0.037	0.007	0.858	**0.189**	1	**0.040**	0.008	0.002	0.796	**0.185**	1	**0.038**	0.007	0.001	0.793
Mexico	**0.181**	1	**0.082**	0.019	0.004	0.831	**0.150**	1	**0.082**	0.016	0.003	0.825	**0.139**	1	**0.081**	0.015	0.003	0.822
Argentina	**0.166**	1	**0.088**	0.020	0.004	0.834	**0.135**	1	**0.086**	0.017	0.003	0.826	**0.125**	1	**0.084**	0.016	0.003	0.823
Switzerland	**0.255**	1	**0.279**	0.067	0.013	0.882	**0.323**	1	**0.367**	0.076	0.015	0.887	**0.346**	1	**0.395**	0.079	0.016	0.888
Belgium	**0.190**	1	**0.133**	0.031	0.006	0.850	**0.192**	1	**0.159**	0.032	0.006	0.851	**0.193**	1	**0.167**	0.032	0.006	0.851
Sweden	**0.216**	1	**0.213**	0.050	0.010	0.870	**0.258**	1	**0.280**	0.057	0.011	0.875	**0.273**	1	**0.302**	0.059	0.012	0.876
Austria	**0.173**	1	**0.077**	0.017	0.003	0.827	**0.171**	1	**0.055**	0.010	0.002	0.807	**0.170**	1	**0.048**	0.009	0.002	0.801
Harmonized global optimum	ω^* = 1		ω^* = 1				ω^* = 1		ω^* = 1				ω^* = 1		ω^* = 1			

Table 2C: Nash Equilibrium and Harmonized Global Optimum
When Price Elasticity of Demand ε=9.28 and Trade Cost t=0

	Price Elasticity of Demand (ε)=1.5 and Trade Cost (t)=0.5																	
	a=0.000315						a=1						a=1.3333					
	$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049				$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049				$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049			
	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i
US	**0.341**	1	**0.390**	0.158	0.032	0.905	**0.365**	1	**0.415**	0.156	0.031	0.905	**0.373**	1	**0.424**	0.155	0.031	0.904
Japan	**0.328**	1	**0.378**	0.150	0.030	0.903	**0.357**	1	**0.408**	0.150	0.030	0.903	**0.367**	1	**0.419**	0.150	0.030	0.903
Germany	**0.274**	1	**0.304**	0.115	0.023	0.892	**0.282**	1	**0.315**	0.110	0.022	0.890	**0.285**	1	**0.318**	0.108	0.022	0.889
France	**0.245**	1	**0.264**	0.097	0.019	0.885	**0.246**	1	**0.266**	0.090	0.018	0.882	**0.246**	1	**0.266**	0.088	0.018	0.881
UK	**0.231**	1	**0.245**	0.088	0.018	0.881	**0.231**	1	**0.246**	0.082	0.016	0.878	**0.231**	1	**0.246**	0.080	0.016	0.877
China	**0.221**	1	**0.223**	0.080	0.016	0.877	**0.211**	1	**0.211**	0.070	0.014	0.871	**0.207**	1	**0.206**	0.066	0.013	0.869
Italy	**0.223**	1	**0.230**	0.082	0.016	0.878	**0.217**	1	**0.223**	0.074	0.015	0.874	**0.215**	1	**0.221**	0.071	0.014	0.872
Brazil	**0.203**	1	**0.198**	0.069	0.014	0.871	**0.193**	1	**0.185**	0.059	0.012	0.865	**0.189**	1	**0.180**	0.056	0.011	0.863
Spain	**0.189**	1	**0.177**	0.061	0.012	0.866	**0.180**	1	**0.164**	0.052	0.010	0.859	**0.176**	1	**0.159**	0.049	0.010	0.857
Canada	**0.204**	1	**0.215**	0.074	0.015	0.874	**0.211**	1	**0.225**	0.072	0.014	0.873	**0.214**	1	**0.228**	0.071	0.014	0.872
India	**0.184**	1	**0.168**	0.057	0.011	0.863	**0.173**	1	**0.152**	0.048	0.010	0.856	**0.170**	1	**0.147**	0.045	0.009	0.853
South Korea	**0.191**	1	**0.191**	0.065	0.013	0.869	**0.192**	1	**0.192**	0.061	0.012	0.866	**0.192**	1	**0.193**	0.059	0.012	0.865
Netherlands	**0.179**	1	**0.174**	0.058	0.012	0.864	**0.181**	1	**0.179**	0.055	0.011	0.862	**0.182**	1	**0.180**	0.054	0.011	0.861
Australia	**0.169**	1	**0.149**	0.050	0.010	0.858	**0.164**	1	**0.143**	0.044	0.009	0.853	**0.163**	1	**0.141**	0.042	0.008	0.851
Mexico	**0.159**	1	**0.122**	0.040	0.008	0.849	**0.148**	1	**0.098**	0.029	0.006	0.837	**0.145**	1	**0.084**	0.024	0.005	0.829
Argentina	**0.148**	1	**0.091**	0.029	0.006	0.836	**0.137**	1	**0.064**	0.019	0.004	0.819	**0.133**	1	**0.064**	0.018	0.004	0.818
Switzerland	**0.177**	1	**0.191**	0.063	0.013	0.867	**0.200**	1	**0.222**	0.068	0.014	0.870	**0.208**	1	**0.232**	0.069	0.014	0.871
Belgium	**0.152**	1	**0.126**	0.041	0.008	0.850	**0.153**	1	**0.129**	0.038	0.008	0.847	**0.153**	1	**0.130**	0.038	0.008	0.847
Sweden	**0.157**	1	**0.152**	0.049	0.010	0.857	**0.172**	1	**0.175**	0.052	0.010	0.860	**0.177**	1	**0.182**	0.053	0.011	0.860
Austria	**0.140**	1	**0.095**	0.030	0.006	0.837	**0.140**	1	**0.095**	0.027	0.005	0.834	**0.140**	1	**0.094**	0.027	0.005	0.833
Harmonized global optimum	ω^* = 1		ω^* = 1				ω^* = 1		ω^* = 1				ω^* = 1		ω^* = 1			

Table 2D: Nash Equilibrium and Harmonized Global Optimum
When Price Elasticity of Demand ε=1.5 and Trade Cost t=0.5 (High Trade Cost Scenario)

	Price Elasticity of Demand (ε)=5 and Trade Cost (t)=0.5																	
	a=0.000315						a=1						a=1.3333					
	$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049				$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049				$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049			
	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i
US	**0.440**	1	**0.500**	0.155	0.031	0.863	**0.500**	1	**0.557**	0.151	0.030	0.862	**0.520**	1	**0.579**	0.150	0.030	0.862
Japan	**0.430**	1	**0.494**	0.150	0.030	0.862	**0.504**	1	**0.563**	0.150	0.030	0.862	**0.529**	1	**0.589**	0.150	0.030	0.862
Germany	**0.339**	1	**0.373**	0.108	0.022	0.849	**0.361**	1	**0.396**	0.100	0.020	0.846	**0.368**	1	**0.409**	0.098	0.020	0.845
France	**0.295**	1	**0.310**	0.087	0.017	0.840	**0.297**	1	**0.314**	0.077	0.015	0.835	**0.298**	1	**0.321**	0.075	0.015	0.834
UK	**0.277**	1	**0.286**	0.078	0.016	0.836	**0.277**	1	**0.287**	0.069	0.014	0.831	**0.276**	1	**0.293**	0.067	0.013	0.830
China	**0.252**	1	**0.236**	0.064	0.013	0.828	**0.226**	1	**0.202**	0.047	0.009	0.817	**0.217**	1	**0.197**	0.044	0.009	0.814
Italy	**0.260**	1	**0.255**	0.069	0.014	0.832	**0.246**	1	**0.239**	0.057	0.011	0.824	**0.241**	1	**0.240**	0.054	0.011	0.822
Brazil	**0.231**	1	**0.202**	0.054	0.011	0.822	**0.205**	1	**0.161**	0.037	0.007	0.807	**0.196**	1	**0.154**	0.034	0.007	0.804
Spain	**0.215**	1	**0.175**	0.045	0.009	0.815	**0.191**	1	**0.122**	0.027	0.005	0.796	**0.182**	1	**0.040**	0.008	0.002	0.752
Canada	**0.254**	1	**0.264**	0.070	0.014	0.832	**0.272**	1	**0.288**	0.067	0.013	0.830	**0.279**	1	**0.302**	0.067	0.013	0.830
India	**0.208**	1	**0.158**	0.040	0.008	0.811	**0.181**	1	**0.053**	0.011	0.002	0.764	**0.171**	1	**0.052**	0.011	0.002	0.761
South Korea	**0.230**	1	**0.220**	0.057	0.011	0.824	**0.231**	1	**0.224**	0.051	0.010	0.820	**0.232**	1	**0.232**	0.050	0.010	0.819
Netherlands	**0.218**	1	**0.204**	0.052	0.010	0.821	**0.224**	1	**0.215**	0.048	0.010	0.817	**0.226**	1	**0.226**	0.048	0.010	0.817
Australia	**0.197**	1	**0.151**	0.038	0.008	0.808	**0.186**	1	**0.125**	0.027	0.005	0.796	**0.182**	1	**0.035**	0.007	0.001	0.746
Mexico	**0.178**	1	**0.075**	0.018	0.004	0.781	**0.150**	1	**0.078**	0.016	0.003	0.777	**0.141**	1	**0.075**	0.015	0.003	0.774
Argentina	**0.164**	1	**0.081**	0.019	0.004	0.783	**0.136**	1	**0.080**	0.017	0.003	0.778	**0.127**	1	**0.078**	0.016	0.003	0.775
Switzerland	**0.242**	1	**0.270**	0.068	0.014	0.831	**0.302**	1	**0.338**	0.075	0.015	0.835	**0.323**	1	**0.365**	0.078	0.016	0.836
Belgium	**0.184**	1	**0.135**	0.033	0.007	0.803	**0.186**	1	**0.141**	0.030	0.006	0.800	**0.187**	1	**0.155**	0.032	0.006	0.802
Sweden	**0.207**	1	**0.208**	0.051	0.010	0.820	**0.244**	1	**0.256**	0.056	0.011	0.823	**0.257**	1	**0.278**	0.058	0.012	0.825
Austria	**0.168**	1	**0.065**	0.015	0.003	0.775	**0.166**	1	**0.055**	0.011	0.002	0.763	**0.166**	1	**0.045**	0.009	0.002	0.754
Harmonized global optimum	$\omega^* = 1$		$\omega^* = 1$				$\omega^* = 1$		$\omega^* = 1$				$\omega^* = 1$		$\omega^* = 1$			

Table 2E: Nash Equilibrium and Harmonized Global Optimum
When Price Elasticity of Demand ε=5 and Trade Cost t=0.5 (High Trade Cost Scenario)

	Price Elasticity of Demand (ε)=9.28 and Trade Cost (t)=0.5																	
	a=0.000315						a=1						a=1.3333					
	$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049				$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049				$\frac{\lambda}{\varepsilon-1}$=1		$\frac{\lambda}{\varepsilon-1}$=1.049			
	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i	ω_i^E	θ^i	ω_i^E	θ_{EX}^i	θ_{FDI}^i	θ^i
US	**0.458**	1	**0.518**	0.154	0.031	0.852	**0.526**	1	**0.585**	0.151	0.030	0.851	**0.550**	1	**0.607**	0.150	0.030	0.851
Japan	**0.450**	1	**0.514**	0.150	0.030	0.851	**0.533**	1	**0.594**	0.150	0.030	0.851	**0.561**	1	**0.620**	0.150	0.030	0.851
Germany	**0.351**	1	**0.383**	0.106	0.021	0.838	**0.375**	1	**0.415**	0.099	0.020	0.835	**0.384**	1	**0.425**	0.097	0.019	0.834
France	**0.304**	1	**0.316**	0.085	0.017	0.829	**0.306**	1	**0.327**	0.076	0.015	0.824	**0.307**	1	**0.331**	0.073	0.015	0.823
UK	**0.286**	1	**0.290**	0.077	0.015	0.825	**0.285**	1	**0.299**	0.068	0.014	0.820	**0.285**	1	**0.302**	0.065	0.013	0.819
China	**0.258**	1	**0.234**	0.061	0.012	0.816	**0.228**	1	**0.205**	0.046	0.009	0.805	**0.218**	1	**0.194**	0.041	0.008	0.801
Italy	**0.267**	1	**0.256**	0.067	0.013	0.820	**0.251**	1	**0.246**	0.055	0.011	0.812	**0.245**	1	**0.243**	0.052	0.010	0.810
Brazil	**0.236**	1	**0.199**	0.051	0.010	0.809	**0.206**	1	**0.162**	0.035	0.007	0.795	**0.196**	1	**0.034**	0.007	0.001	0.735
Spain	**0.219**	1	**0.170**	0.042	0.008	0.802	**0.192**	1	**0.041**	0.008	0.002	0.743	**0.182**	1	**0.043**	0.008	0.002	0.743
Canada	**0.263**	1	**0.272**	0.069	0.014	0.821	**0.284**	1	**0.305**	0.067	0.013	0.820	**0.291**	1	**0.316**	0.066	0.013	0.819
India	**0.211**	1	**0.149**	0.037	0.007	0.797	**0.181**	1	**0.053**	0.011	0.002	0.752	**0.170**	1	**0.056**	0.011	0.002	0.752
South Korea	**0.237**	1	**0.223**	0.056	0.011	0.813	**0.239**	1	**0.236**	0.051	0.010	0.809	**0.239**	1	**0.240**	0.049	0.010	0.808
Netherlands	**0.225**	1	**0.208**	0.051	0.010	0.809	**0.232**	1	**0.228**	0.048	0.010	0.807	**0.234**	1	**0.235**	0.048	0.010	0.807
Australia	**0.202**	1	**0.147**	0.035	0.007	0.796	**0.189**	1	**0.037**	0.007	0.001	0.738	**0.185**	1	**0.036**	0.007	0.001	0.735
Mexico	**0.181**	1	**0.079**	0.018	0.004	0.772	**0.150**	1	**0.078**	0.016	0.003	0.766	**0.139**	1	**0.076**	0.015	0.003	0.763
Argentina	**0.166**	1	**0.083**	0.019	0.004	0.773	**0.135**	1	**0.081**	0.016	0.003	0.767	**0.125**	1	**0.079**	0.015	0.003	0.764
Switzerland	**0.255**	1	**0.284**	0.069	0.014	0.821	**0.323**	1	**0.364**	0.077	0.015	0.825	**0.346**	1	**0.390**	0.079	0.016	0.826
Belgium	**0.190**	1	**0.133**	0.031	0.006	0.791	**0.192**	1	**0.154**	0.031	0.006	0.791	**0.193**	1	**0.161**	0.031	0.006	0.791
Sweden	**0.216**	1	**0.217**	0.052	0.010	0.810	**0.258**	1	**0.278**	0.057	0.011	0.814	**0.273**	1	**0.297**	0.059	0.012	0.815
Austria	**0.173**	1	**0.068**	0.015	0.003	0.765	**0.171**	1	**0.049**	0.009	0.002	0.747	**0.170**	1	**0.043**	0.008	0.002	0.742
Harmonized global optimum	ω^* = 1		ω^* = 1				ω^* = 1		ω^* = 1				ω^* = 1		ω^* = 1			

Table 2F: Nash Equilibrium and Harmonized Global Optimum
When Price Elasticity of Demand ε=9.28 and Trade Cost t=0.5 (High Trade Cost Scenario)